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UNMANNED AERIAL VEHICLE SURVIVABILITY: THE IMPACTS OF SPEED, DETECTABILITY, ALTITUDE, AND ENEMY CAPABILITIES

by

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September 2005

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13. ABSTRACT (maximum 200 words)

Warfighters are increasingly relying on Unmanned Aerial Vehicle (UAV) systems at all levels of combat operations. As these systems weave further into the fabric of our tactics and doctrine, their loss will seriously diminish combat effectiveness. This makes the survivability of these systems of utmost importance. Using Agent-based modeling and a Nearly Orthogonal Latin Hypercube design of experiment, numerous factors and levels are explored to gain insight into their impact on, and relative importance to, survivability. Factors investigated include UAV speed, stealth, altitude, and sensor range, as well as enemy force sensor ranges, probability of kill, array of forces, and numerical strength. These factors are varied broadly to ensure robust survivability results regardless of the type of threat. The analysis suggests that a speed of at least 135 knts should be required and that increases in survivability remain appreciable up to about 225 knts. The exception to speed's dominance is in the face of extremely high capability enemy assets. In this case, stealth becomes more important than speed alone. However, the interactions indicate that as both speed and stealth increase, speed yields a faster return on overall survivability and that speed mitigates increased enemy capabilities.

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UNMANNED AERIAL VEHICLE SURVIVABILITY: THE IMPACTS OF SPEED, DETECTABILITY, ALTITUDE, AND ENEMY CAPABILITIES

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ABSTRACT

Warfighters are increasingly relying on Unmanned Aerial Vehicle (UAV) systems at all levels of combat operations. As these systems weave further into the fabric of our tactics and doctrine, their loss will seriously diminish combat effectiveness. This makes the survivability of these systems of utmost importance. Using Agent-based modeling and a Nearly Orthogonal Latin Hypercube design of experiment, numerous factors and levels are explored to gain insight into their impact on, and relative importance to, survivability. Factors investigated include UAV speed, stealth, altitude, and sensor range, as well as enemy force sensor ranges, probability of kill, array of forces, and numerical strength. These factors are varied broadly to ensure robust survivability results regardless of the type of threat. The analysis suggests that a speed of at least 135 knts should be required and that increases in survivability remain appreciable up to about 225 knts. The exception to speed's dominance is in the face of extremely high capability enemy assets. In this case, stealth becomes more important than speed alone. However, the interactions indicate that as both speed and stealth increase, speed yields a faster return on overall survivability and that speed mitigates increased enemy capabilities.

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THESIS DISCLAIMER

The reader is cautioned that the computer programs presented in this research may not have been exercised for all cases of interest. While every effort has been made, within the time available, to ensure that the programs are free of computational and logical errors, they cannot be considered validated. Any application of these programs without additional verification is at the risk of the user.

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My Lord and Savior, Jesus Christ

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EXECUTIVE SUMMARY

Warfighters are increasingly relying on Unmanned Aerial Vehicle systems at all levels of combat operations. As these systems weave further into the fabric of our tactics and doctrine, their loss will seriously diminish combat effectiveness. This makes the survivability of these systems of utmost importance. The Marine Corps is begining the process of defining the desired design characteristics for its next generation Vertical Unmanned Aerial Vehicle. Survivability must be integrated early in this process to ensure maximum effectiveness on the battlefield. However, many questions regarding survivability of a UAV need to be answered. How does speed, stealth, sensor range or tactical employment affect survivability? How do these answers change against different threat scenarios and capabilities? With limited budget resources what characteristics should be focused on?

Using the agent-based model MANA and a scenario based upon the Sea Viking 04 Fleet Battle Experiment, the impacts of speed and detectability on survivability are explored. See Figure S1. Many additional factors are also included to ensure robust solutions that are not dependent upon model assumptions or enemy capabilities. A Nearly Orthogonal Latin Hypercube design of experiment allows the exploration of numerous factors at multiple levels without the enormous computing burden of a full factorial design. The efficiency of the design provides a basis to perform in depth statistical analysis. UAV characteristics explored include speed, stealth, altitude, sensor range, next waypoint attraction and enemy attraction. Enemy force sensor ranges, probability of kill, array of forces, and numerical strength are also varied in the simulation runs.

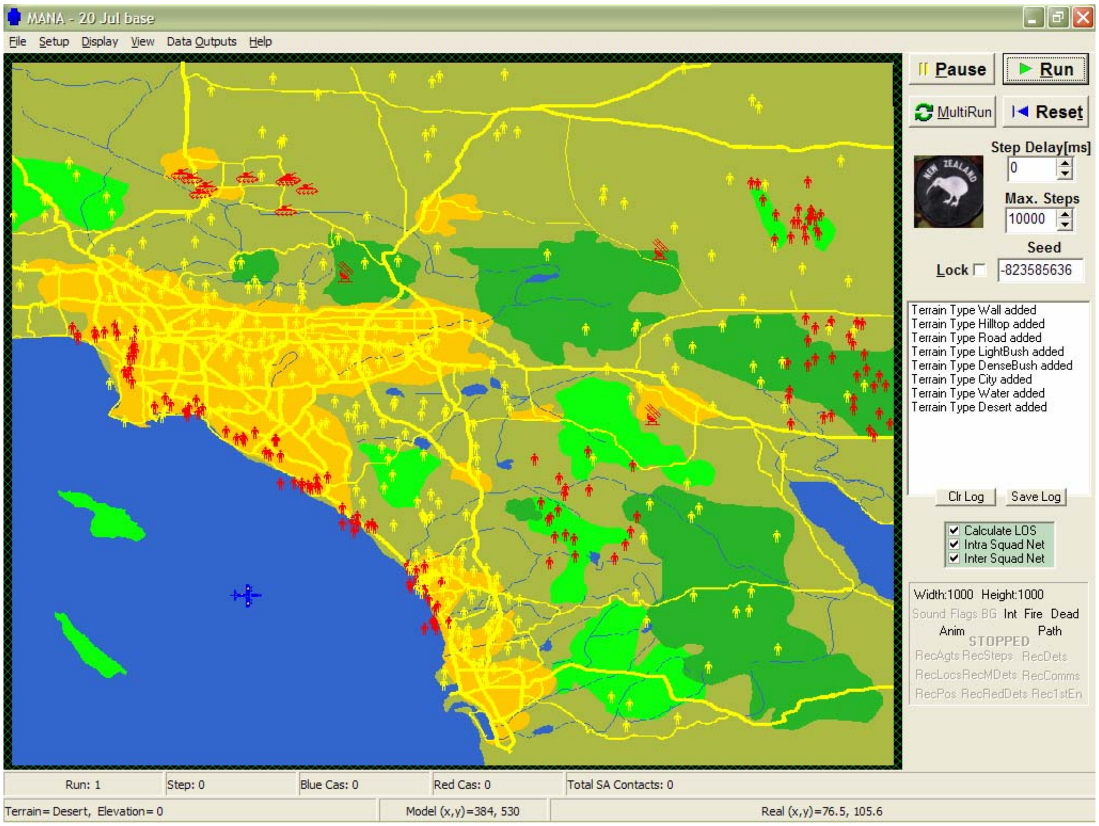

Figure S1. A Screen Shot of the MANA Simulation Used to Explore UAV Survivability.

Twelve root factors at 65 levels, 42 additional related variables, ten scenario variations, and 100 replications per design point provide 65,000 data points generated at the Maui High Performance Computer Center. The data is primarily analyzed using Stepwise Multiple Linear Regression and Classification and Regression Trees. Within the scope of this model, the analysis suggests:

- A speed of at least 135 knts should be required and that increases in survivability remain appreciable up to about 225 knts.
- The exception to speed's dominance is in the face of extremely high enemy capability assets. In this case, stealth becomes more important than speed alone.
- The interactions indicate that as both speed and stealth increase, speed yields a faster return on overall survivability even in presence of high enemy capability. See Figure S2.

- Speed mitigates increased enemy capabilities.
- Stealth, as a reduction of enemy senor range is, in general, the second most important characteristic. Its importance increases as enemy capabilities increase and as altitude increases.
- Increased altitude produces higher mean survivability as well as decreased variability.

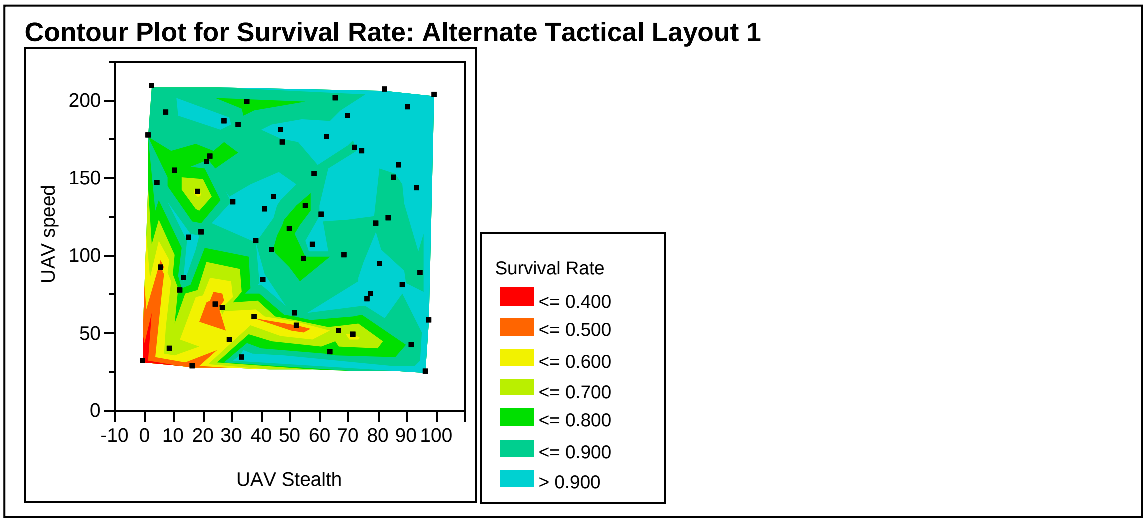

Figure S2. Contour Plot Showing the Interaction between UAV Speed and Stealth. Note that at slower speeds more than 80% stealth is required to enhance survivability but at higher speeds much less stealth provides the same survivability. (Speed scale is approximately knots divided by 2.)

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I. INTRODUCTION

A. PURPOSE

> OIF experience argues for a robust (UAV) capability that can provide 24-hour coverage to both the Division and one Regimental Combat Team (RCT) (the Main Effort). [**OPERATION IRAQI FREEDOM:** LESSONS LEARNED (1st MarDiv, 2003)]

The purpose of this research is to assist the Marine Corps in identifying requirements for future Unmanned Aerial Vehicles (UAVs). This is done by exploring the effects of various UAV characteristics on survivability, primarily focusing on speed and detectability. Other aspects such as, sensor range, altitude, and employment methodology are included. These characteristics are analyzed in the face of a broad range of enemy capabilities and varying threat scenarios. The results provide insight on desired design characteristics for both the interim replacement* for the Pioneer and the follow-on Vertical Unmanned Aerial Vehicle (VUAV).

B. BACKGROUND

One of the initial motivations that served as impetus for developing Unmanned Aerial Vehicles (UAVs) was that UAVs would be inexpensive. They could be launched into high risk missions without risking a costly manned aircraft and the lives of its crew. As the complexity and the utility of UAVs grow, the cost of losing these assets becomes increasingly important. Survivability of the UAV, which has been considered a secondary issue for a disposable piece of gear, is now of primary importance due to the cost, high demand, and low availability of these assets that are performing mission essential tasks in ever expanding missions and payloads. More importantly, war-fighters are depending upon these assets. The loss of a UAV directly affects combat effectiveness.

As we look at the changing face of warfare, an increased reliance on real-time information and a broader communications reach will be essential to the success of future operations. The Marine Corps' Expeditionary Maneuver Warfare doctrine stresses speed

* As of the printing of this thesis, current plans no longer include an interim system as Pioneer is to be extended until VUAV is operational.

and a quick strike at enemy vulnerability. This necessitates high-resolution intelligence that supports the spectrum of combat operations from Stability Operations to Major Combat Operations (EMW, Nov 2001). UAVs will satisfy much of this essential intelligence requirement using more sophisticated and costly equipment, again highlighting the need for both survivable design and employment. Recent history bears this out as UAVs have moved from limited roles in places like the first Gulf War and other conflicts to high demand integrated assets at all levels of warfare, as we have seen in Operation Iraqi Freedom (OIF), and the Global War on Terrorism (GWOT) in Afghanistan and around the world. Andrew Krepinevich, in his report *Operation Iraqi Freedom: A First Blush Assessment*, stated the following:

> During the First Gulf War, UAVs were a sideshow, at best. By the late 1990s, however, UAVs were coming into their own. In Operation Allied Force, UAVs were used to probe Serbian air defenses, identify targets, monitor ethnic cleansing, perform electronic intelligence operations, assess bomb damage to targets, jam Serbian communications, and act as airborne communication relays…. Given their performance in these three recent conflicts (OAF, OIF, and GWOT), the role of UAVs seems certain to expand in the future. However, if and when enemy air defense systems become more formidable and the anti-access threat matures, the US military will likely require a significant number of stealthy, extended-range UAVs to maintain the kind of persistent surveillance it found so valuable in Operation Iraqi Freedom. (Krepinevich, 2003)

This leads to the following questions regarding survivability: what are the best characteristics for a UAV to have? Should more money be spent on stealth, speed, or sensor capability? Should they fly at high, medium, or low altitudes? How should they be employed tactically? The focus of this work is on how speed and detectability impacts the survivability of a UAV. It is important to note that asking these same questions regarding UAV effectiveness may yield different, even contrary, results. In the extreme case, a UAV that never leaves the ground has perfect survivability, but the resulting efficiency is nil. However, these two measures, survivability and effectiveness, are not always diametrically opposed. Certain combinations of qualities may yield desired results, for example, a slow vehicle that is efficient could be coupled with high stealth value for survivability.

C. MOTIVATION

The RQ-2 Pioneer Unmanned Arial Vehicle has served the United States Marine Corps since the mid 1980s and has proven the value of UAV assets, most recently in Operation Iraqi Freedom and Operation Enduring Freedom. However, it is now reaching the end of its service life and will retire from service in 2008. The Marine Corps System Command is in the process of selecting a replacement. Both the Functional Needs Analysis and Concept of Operations documents are complete. (Vertical Unmanned Aerial Vehicle (VUAV) Functional Need Analysis, Marine Corps System Command, 2004; Vertical Unmanned Aerial Vehicle Concept of Operations, Marine Corps System Command, 2004) However, due to the imminence of Pioneer's retirement, an interim replacement will be required. This will be selected from a range of currently available equipment, including UAVs such as Fire Scout and Eagle Eye, pictured in Figure 1. The selected system will bridge the gap between the retiring Pioneer and the development and deployment of the long term replacement known as Vertical Unmanned Arial Vehicle (VUAV).

Figure 1. Eagle Eye (top) and Fire Scout UAVs. Two Possible Interim Systems for the Marine Corps.

The VUAV will fill the needs of the future Joint Task Force (JTF) and Marine Air Ground Task Force (MAGTF) commanders in an integrated environment in the 2015 time frame. This VUAV will support the warfighter through enhancing Dominant Maneuver, Precision Engagement, and Full Dimensional Protection (VUAV ConOps, 2004). The VUAV Concepts of Operations envisions a system that will be capable of speeds up to 260 knots and a range of 319 nm with a 1.5 hour on station time. It will be deployable from a ship or an austere, land-based environment. With a suite of available sensor packages, communications equipment and/or (an eventual) strike capability, it will feed information to all appropriate agencies in the battle space network. Exactly what these and other characteristics need to be to enhance the survivability of this system has yet to be determined. Using Marine Corps simulation tools, this thesis explores a wide range of characteristics that effect platform survivability.

The Marine Corps Warfighting Lab's Project Albert has developed a suite of simulation tools and data analysis techniques for Data Farming. Data Farming is:

> a method to address decision-maker's questions that applies high performance computing to modeling in order to examine and understand the landscape of potential simulated outcomes, enhance intuition, find surprises and outliers, and identify potential options. Data Farming is the method by which potentially millions of data points are explored and captured. (Dr. Gary Horne, Director Project Albert, Project Albert Web site, accessed April 2005)

One of the simulation tools they use, called Map-Aware Non-Uniform Automata (MANA), was developed by the New Zealand Defense Technology Agency. MANA is an agent-based distillation where each entity represented has its own guiding set of state dependent principles that govern its behavior. Because of this, MANA is very useful for exploring the wide range of possible outcomes in any given scenario. This capability is used to explore the effects of varying characteristics of the VUAV over a range of enemy capabilities and scenarios.

Captain Mark Raffetto's recently completed thesis work addresses some of the essential capabilities of the VUAV in terms of mission efficiency; that is, what characteristics maximize the ability to detect and classify targets (Raffetto, 2004). This research addresses the capabilities of the VUAV in terms of platform survivability. That is, the characteristics required to maximize the survivability of the VUAV. The two analyses are complementary and combine to give the decision maker a more complete decision making tool. When coupled together with the results of Raffetto, characteristic sets can be evaluated, and the trade off space between effectiveness and survivability, along with areas where both can be achieved, can be explored. This yields valuable insight for decision makers as the VUAV program evolves, allowing a foundational set of desired characteristics to be selected for the VUAV early in the development and acquisition process.

D. DEFINITION AND FOCUS

Survivability, by definition, has two parts: susceptibility and vulnerability. Susceptibility is a platform's lack of ability to avoid munitions. In other words, it is the absence of being able to keep someone else's weapon system from hitting it. Vulnerability, on the other hand, is the lack of ability to continue with a mission once the platform has been hit (Ball, 2003).

The focus in this study is on susceptibility rather than vulnerability, the assumption being that any hit will cause serious damage or destruction. In reduced terms, the question here is, "can I use it again or not?" The purpose of this thesis will be to explore the impacts of speed, endurance, and altitude characteristics on the susceptibility aspects of survivability of the VUAV platform.

E. SCOPE, LIMITATIONS, AND ASSUMPTIONS

With the technique of Data Farming and a Nearly Orthogonal Latin Hypercube (NOLH) Design of Experiments, both a large number of parameters and levels within each parameter are sampled. Parameters are varied both below and beyond expected future capabilities, both friendly and enemy. There are two reasons for approaching the problem in this manner. First, it makes the results much less dependent on the input data —yielding a more robust solution. In this way, results are still relevant when details of the model inputs change. Second, future capability assessments may be over- or underestimated. Technology may develop much faster than anticipated or unforeseen problems may make other capabilities unrealizable within the period of interest. The only thing that is certain about the future is that it will not be exactly as we think. The design of the VUAV must be survivable in all situations and threat environments, not just in a single anticipated scenario. This requires a robust solution set.

Despite the advanced techniques just mentioned, this is still a model. As George Box said, "All models are wrong, some are useful." This model is not reality and the results are not absolute. The utility of the results are in comparisons between the values of each set of parameters across the scenario sets. They will allow determination of which combinations are better than others and what restrictions, if any, apply. They will not say that a given UAV, with a given set of characteristics, has a 90% survivability rate per mission, but rather which set of characteristics will give us the highest survivability rate over varied scenarios, as well as in particular scenarios, within the scope of this thesis.

It is important to note both the assumptions that are being made and those that are not. The model assumes that the selected UAV, or system of UAVs, has the resources to fly the entire mission. This is a big assumption as the area covered in this scenario is beyond the current capabilities of a single UAV of the typical size used at this echelon. The model also assumes that if a UAV is hit it is destroyed. This assumption may not be realistic, but it serves to isolate the effects of the parameters being explored and not to confound them with the vulnerability of the UAV. More details on the scenario specific assumptions are given in Chapter II.

Due to the tremendous effort typically associated with creating a single scenario in a simulation, results often rest on a very narrow edge of assumptions. Consequently, slight changes in the assumptions can have disproportionate effects on the results. With MANA's agent-based design and an XML script tool called The Tiller,* all significant parameters of the scenario can be varied in multiple runs. Therefore, many typical assumptions are avoided and a more robust solution is obtained. Some assumptions that are typical in simulations but are not being made here are: no fixed enemy capability, no fixed enemy tactical deployment, no fixed UAV characteristics, and no assumed employment tactics.

The characteristics that are explored fall into the three main categories listed below:

- UAV design characteristics:
    - speed, stealth, sensor range, and altitude
- UAV tactical employment considerations:
    - tendency to move toward enemies, unknowns, and next waypoint

* The Tiller was designed by Steve Upton of Referentia Systems Incorporated for Project Albert.

- Enemy characteristics:
    - numbers and types of systems
    - proficiency/accuracy
    - tactical layout of forces

F. THESIS FLOW

The next chapter will introduce the Sea Viking scenario on which the models built are based. It will also discuss the methodology that is applied to this research, as well as the selected factors and source data. Chapter III will go into detail on the build up of the base model, highlighting implementation of desired effects and behaviors. This will lead into the variations created from the base model and the aspects covered that could not be addressed in the base model design of experiment. In Chapter IV, analytical techniques are briefly explained. Examples of each technique are given noting both strengths and weaknesses. Chapter V gives a thorough discussion of the analysis of each scenario as well as conclusions and recommendations. Supporting documentation on input data and the complete analytical work is contained in the Appendices.

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II. DATA AND METHODOLOGY

This chapter discusses the scenario on which the simulation model is built. A brief description of the simulation tool, MANA, and some of its key features follow. The methodology used is then addressed with an overview of Data Farming and the application of the Nearly Orthogonal Latin Hypercube (NOLH) design of experiments. The chapter concludes with discussion on which factors are of interest and how they are modeled.

A. SCENARIO

The Marine Corps Warfighting Lab's (MCWL) Sea Viking Program is the "live experimentation pathway that develops and assesses warfighting capabilities through live force experimentation." (MCWL Web site, accessed 04 April 05). As part of their "Combined Arms attack on Naval transformation," it combines the exploration of innovative technology and techniques in both virtual environments and live Fleet experiments. Sea Viking 04 was designed primarily to gain understanding of sea-based Expeditionary Maneuver Warfare and future Naval command and control (C2) relationships in the Ship-to-Objective Maneuver concept.

The setting of Sea Viking 04 is that of a Southeast Asian island nation that has a splinter government group attempting to establish an independent country. The rebels have taken control of considerable military assets in their region. The legitimate government has asked for assistance from the United States and the United Nations. The live experiment was imposed upon the southern California military complex region to include Naval Base San Diego, Marine Corps Air Station (MCAS) Miramar, Marine Corps Base (MCB) Camp Pendleton, March Air Reserve Base, MCAS Yuma, MCB 29 Palms and surrounding areas. See Figure 2 for a map of this area.

The live experiment portion of Sea Viking 04 never took place due to operational commitments around the world, but the scenario is used for this model for several reasons. First, it provides a recognized and approved setting in terms of mission and threat. Second, it provides a comparative basis of analysis between this work and the work of Raffetto, providing a more complete decision maker's tool. Finally, Raffetto had built the scenario in MANA, saving valuable initial start up time. Some modifications to the original model were necessary; however, care has been taken to preserve the general behavior of the model in order to retain continuity.

Figure 2. Area of Operation for Sea Viking 04 Live Experiment. (Best viewed in color)

The portion of Sea Viking modeled in this study begins in the opening stages of U.S. force arrival. UAVs are selected to do area reconnaissance for the Marine Expeditionary Force (MEF) that has just arrived off the coast. The model encompasses an area 150 nm by 150 nm. The enemy forces are tactically dispersed throughout the area. Refer to Figure 3 for placement of forces and numbering. Group 1 consists of Coastal Infantry that is stretched along the western coast. Group 2 is Low Country Infantry; group 3, Mountain Infantry; and group 4, Objective Area Infantry. Group 5 is a Tank Battalion moving southeast to take up a blocking position near the pass. Group 6 is made up of Air Defense Assets.* The only US force modeled in the simulation is the

* Air Defense Assets are referred to as Time Critical Targets (TCTs) in Raffetto's model.

UAV itself. The UAV begins on board a notional US ship and travels a planned route through the area of interest. A number of neutral civilians are also included.

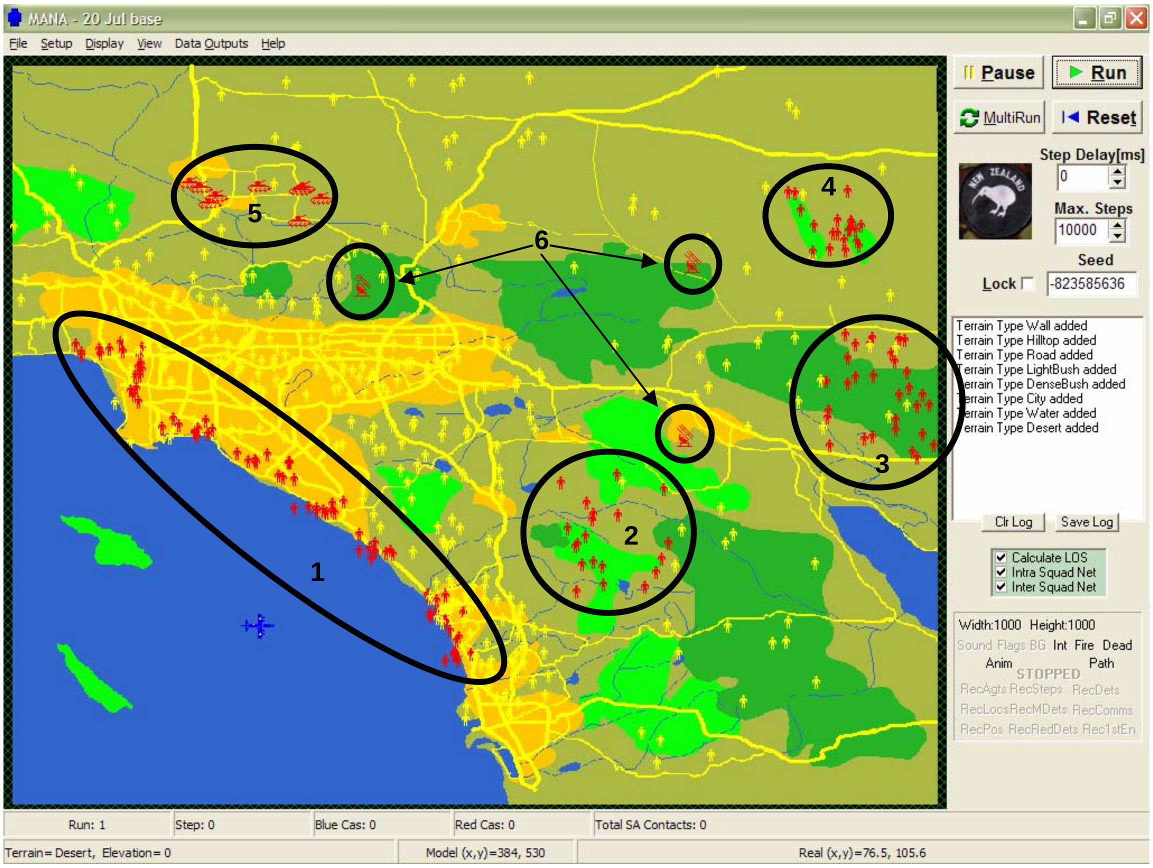


Figure 3. Initial Position of Forces.

It is important to note here that the route given the UAV to reconnoiter is on the order of 450 nm in length. There is currently no MEF level UAV that has the ability to cover such a distance. These platforms could be chained, relay style, to cover the assigned area. Some proposed systems, Eagle Eye, for example, have the endurance for such a route. The limiting factor then becomes the communication link between the UAV and the ground control station, which is limited to line of sight. Barring intervening high terrain, this gives a range of approximately 40 to 100 nm at 1000 to 5000 ft altitudes. Satellite communications would overcome this limitation, but this assumes the presence of an available satellite dedicated to provide coverage of the area. Alternatively, an additional UAV could be used as a communication relay to increase control and data links. For the purposes of this research, it is assumed that the endurance and communication link capabilities exist to cover the entire route. This assumption does not affect the impact of the studied factors on survivability; although it would affect raw survivability rates due to the possible increased exposure of multiple assets.

B. MAP AWARE NON-UNIFORM AUTOMATA (MANA)

The combat simulation tool used in this research is Map Aware Non-Uniform Automata or MANA. The previous figure is a screen shot from MANA. The New Zealand Defense Force developed MANA in response to deficiencies noted in current agent-based models. The intuitive graphical user interface makes setting up and manipulating scenarios easy. As in all agent-based models, each entity in MANA is guided in its behavior by its own set of personality traits. Each MANA agent has a situational awareness map on which it keeps track of all contacts; hence, agents are "Map Aware. The agents are "Non-uniform" because an agent's movement is determined by combining information from its situational awareness (SA) map and surrounding terrain, with its personality traits. MANA evaluates this movement algorithm for every agent, in random order, at each time step.

Each entity within the same "squad" has the same set of personality traits, weapons, communication links, and ranges. Communications involve optional links within and among squads. Agents share user-selected information from the sender's SA map over these links. Information from one's own squad is known as organic SA. Information provided from outside one's own squad is inorganic SA.

One of the key features of MANA is that an agent's personality traits can change when particular events occur. These state changes can be set to take place when the event happens to the individual, its squad (organic), or other squad (inorganic). For example, a state change may occur if an agent is shot at. This may make the agent have a greater desire to move toward cover or move more slowly. Similarly, a state change may be triggered by another squad member firing at the enemy, or it may be triggered by another squad gaining contact with neutrals. Any of the wide array of agent settings can be changed according to state. The duration of the state is set by the user and a fall back state may be selected to chain different states together. As the simulation progresses, each individual changes state, moves, and shoots according to its own situational awareness map of its environment. Stochastic elements are introduced in both movement and probability of hit for shots taken. Therefore, no two runs are alike, unless started with the same random number seed, so that multiple runs will yield a distribution of outcomes over a given set of input values. More information on MANA may be found in the MANA Users Manual (Galligan, 2004).

This ability to explore a range of outcomes is one of the great strengths of agent-based models. Tremendous insight can be gained by seeing not just the most likely outcome but also the realm of possible outcomes. A sense of the degree of variation is gained and the severity of unlikely results can be assessed. This is the basic idea behind Data Farming, which will be discussed in the next section.

As noted in Ball, there are many available physics-based simulations that are used to predict aircraft survivability (Ball, 2003, pp 141-154). These simulations take into account the flight path of the munitions, angle of intercept, proximity at detonation, and fragmentation patterns in conjunction with platform characteristics of material, signatures, and countermeasures. MANA does not evaluate engagements on this physics-based level. MANA adjudicates an engagement based solely on probability of hit given detection. This methodology has the advantage of allowing exploration of a broader range of factors that may influence survivability: i.e., not just physical attributes. By keeping out of the realm of engineering, we can discover which aspects are important to focus on in the design process. In this way, we may find out whether stealth or speed is more important, so spend money on one and not the other. Alternatively, we may see that the highest survivability payoff is in the tactical employment of the UAV. Additionally, we can see the trade-off space between factors. For instance, if speed is cheaper than stealth, one can determine how much speed is required to match a given survivability level.

C. DATA FARMING

Data Farming is:

> …a method to address decision-maker's questions that applies high performance computing to modeling in order to examine and understand the landscape of potential simulated outcomes, enhance intuition, find surprises and outliers, and identify potential options. Data Farming is the method by which potentially millions of data points are explored and

captured. (Dr. Gary Horne, Director Project Albert, Project Albert Home Page)

The idea here is this: if you look at one factor and sample it at one value in a deterministic model, you get one result for that point. If you sample at two values, say at a high and a low level, you can see the effect of changing that factor, but you do not really know how it behaves in between those points. If you vary that factor over a range of values, you can see the effect of that factor on the results over the whole range. Still, it is not perfect — that would require sampling at every point — but you can get a much better reflection of the real effect of the change in the factor as more points are sampled. Now, move this idea to a stochastic model where each point is sampled a sufficient number of times to get a distribution of outcomes for that point. When we do this over a range of values, we get an idea of the topography of the distribution over the range of values. That is, we see the change in distribution due to the change in factor level. See Figure 4 for a graphical representation of this idea. Finally, we apply this idea not to one factor but many factors sampling at sufficient points to analyze both simple effects and interactions. This requires the power of high performance computing to generate or "grow" tens or hundreds of thousands of runs and then "cultivate" the data for analysis.

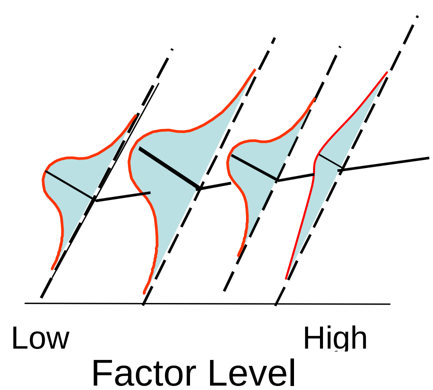


Figure 4. Distribution of Outcomes Over a Range of Values for One Factor. (after Nussbaum, 2005)

The next question is how to design an experiment that can generate the appropriate data over many factors in sufficient volume to be analytically significant. The following section discusses this issue with a design of experiment technique known as a Nearly Orthogonal Latin Hypercube.

D. DESIGN OF EXPERIMENTS AND NEARLY ORTHOGONAL LATIN HYPERCUBES

The challenge in conducting this type of experiment is in the "curse of dimensionality." If there are three factors and each factor has two levels, we need to make $2 \times 2 \times 2$, or $2^3 = 8$ design points to cover all the possible combinations. In general, we need L^F design points where F = number of factors and L = number of levels of each factor. This is known as a full factorial design. As we raise the number of factors and desired levels to accommodate the idea of Data Farming, we see that the number of design points quickly gets out of hand. For example, five factors at five levels yield 3,125 design points, and 17 factors at 65 levels yield nearly 6.6×10^{30} design points. Even with supercomputing power, a design of this size would literally take millennia to run. We just do not have that kind of time.

A Nearly Orthogonal Latin Hypercube design of experiment addresses how to sample the design space without looking at all possible combinations. Although it is beyond the scope of this thesis to explain in detail how and why this works, the following example illustrates the general idea. Consider a design of three factors, each with two levels, high and low. Picture the design space as a cube and the points sampled as the vertices of the cube corresponding to the different possible combinations of factors: high, high, high; high, high, low; etc., see Figure 5. Known as a 2^n Factorial Design, this design samples the space at each of the eight corners; however, it does not sample any of the space *inside* the cube. If we randomly chose some points from the inside, we would begin to get a glimpse of what is going on in the interior. This is the idea behind a Random Latin Hypercube. If we select those interior points such that the correlation between factor levels is very low we get a much more complete picture of the landscape from which we are sampling. This is a Nearly Orthogonal Latin Hypercube. In addition, the low correlation and the large number of design points allow the analysis of both main effects and interactions between factors without sampling at all combinations of levels of each factor.* For more information on Nearly Orthogonal Latin Hypercube design, see Cioppa (2002).

* Sampling at all combinations of all level of each factor is known as a Full Factorial Design. For more information on Full Factorial and 2^n Factorial Designs see Law and Kelton, (2003).

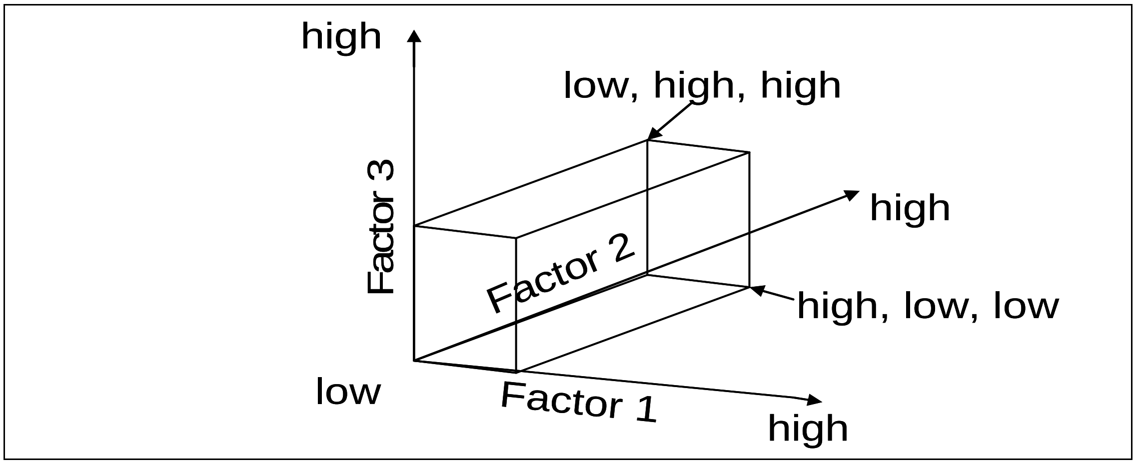


Figure 5. 2^n Factorial Design for Three Factors. The vertices of the cube represent the design points. Note that none of the space inside the cube is sampled.

In the past, simulations have often only been able to yield results with a very narrow scope. Those results were tightly tied to model assumptions and if those assumptions were off by a slight margin, the results could change dramatically. For instance, running a simulation with a particular set of enemy probability of kill (Pk) values and a fixed tactical layout would allow one to find an optimal set of UAV characteristics that maximize survivability. However, this result is only applicable for that particular set of assumptions. A slight improvement in enemy capabilities or a different arrangement of forces may drastically change the resulting optimal values. By the application of Data Farming and NOLH, a very broad parameter space can be explored and robust solutions can be found. A robust solution may not be the optimal choice for any given set of parameters, but is a good overall choice given a variety of possibilities.

E. FACTORS AND VARIABLES

The MANA simulation environment allows a modeler to manipulate a large range of factors, providing superior flexibility in design implementation. Each of the chosen factors is then varied to assess their impact on UAV survivability. The factors varied in this research can be broken into two groups, controlled and uncontrolled. Controlled factors are those that are directly controllable by the user. For example, UAV speed can be controlled in both the design stage and by the operator during use. Similarly, stealth is controlled by designing the UAV to have a particular radar cross section, or noise and heat signatures. Uncontrollable factors can either not be influenced by or are unknown to the user *à priori*. These are usually associated with enemy traits, such as weapon systems capabilities, operator proficiency, tactical layout of forces, etc.

Both controllable and uncontrollable factors are varied here. Clearly, the controllable factors are varied to find superior combinations for increased survivability. Uncontrollable factors are varied for two reasons. First, these factors are usually not known with certainty and they can vary widely depending on the enemy against which the battle is fought. As discussed previously, results should not be dependent upon this kind of assumption. Second, some UAV characteristics are best explored by modeling their effect on the enemy rather than explicitly changing a UAV characteristic. As an example, stealth in MANA is modeled explicitly for an agent by reducing the probability that that agent will be seen by another agent on any given time step. Therefore, a 50% stealth value allows an agent to be seen, on average, half the time when in another agent's sensor range. This is not necessarily, how stealth would be manifested by a UAV. Stealth should have the effect that at longer ranges the UAV is not seen at all and then at some closer range it can be picked up with some probability. This can be modeled in MANA by varying the enemy's sensor ranges in combination with varying its stealth value. A similar case exists for modeling altitude. MANA has limited altitude modeling abilities and is essentially a two dimensional model. The effect that flying at a higher altitude has on survivability, however, can be modeled by reducing weapons ranges in accordance with the geometry of slant range projections onto a two dimensional space, see Figure 6. In each of these cases, an "uncontrollable" factor is varied to express the effect of controllable factors.

The ranges used for each factor are based on open source information, including various information and program Web sites as well as Jane's reference data. These values are expanded in both directions in order to incorporate the widest variety of capabilities both anticipated and unanticipated. For analysis of classified weapons data values, see the classified Appendix D.

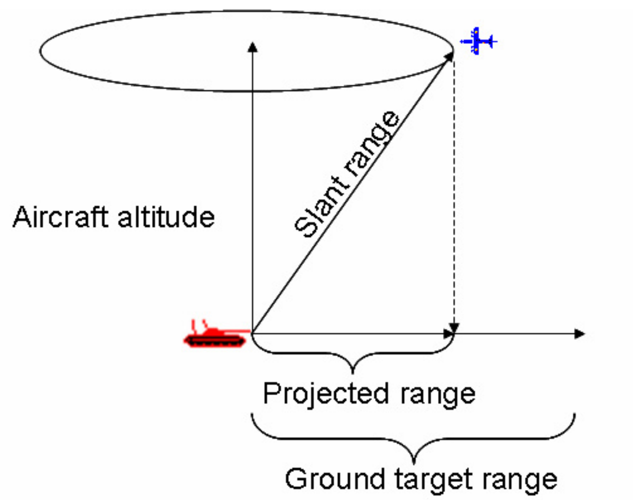


Figure 6. Slant Range Projections onto Two-dimensional Space.

III. THEME AND VARIATIONS: SCENARIO BUILDS

"Vision without execution is hallucination" — Thomas Edison

This chapter describes how the basic scenario is modeled. It also describes the nine variations derived from the base model and the purpose for each. The model from Raffetto is used as a starting point. Changes and additions noted emphasize the aspects of the modeling effort that highlight how the variables of interest are implemented in MANA. Care is taken to maintain the same general behavior for purposes of continuity and comparison. No model can perfectly represent reality, but the simulation tool can be used to gain insights into particular facets of the question at hand. In this case, survivability of the UAV is the focus of effort, and all behavior implementations reflect this.

A. BASE MODEL

Sea Viking 04 provides the scenario for the modeling effort. A more complete description is found in Chapter II, but a brief synopsis is given here. A splinter government group has taken control of significant military assets on an island nation and threatens a violent break from the legitimate government. A request for help from the legitimate government goes out to the United Nations and the United States responds. The first forces into the area are an Expeditionary Strike Group, including a Marine Expeditionary Unit on board an Amphibious Ready Group. As the forces approach the coast, UAVs are tasked with an Information, Surveillance, and Reconnaissance (ISR) mission. Flying at 1,000 ft above ground level (AGL), the UAV is assigned a tactical routing that will bring it over likely areas of enemy concentration and likely friendly avenues of approach, based on the terrain and objectives. Raffetto determined such a tactical routing to be most efficient and it is used here in all variations. (Raffetto, 2004)

The enemy forces modeled are Infantry, Tanks, and Air Defense Assets (ADA). Like Raffetto's model, forces are aggregated such that one enemy agent in the simulation represents three real world entities (infantry soldier, tank, or ADA). The justification for doing so, however, is different. Raffetto's MOE was the percentage of enemy identified per hour. After comparing selected aggregated and un-aggregated models, he found consistent identification rates between them. The aggregated model reduced runtime. Here, the aggregation is used to define an enemy where not every infantry man has a weapon that can range a UAV, even at 1000’ AGL. Additionally, neither Infantry, Tanks, nor ADA are likely to commit all of their resources to a UAV. These assumptions are disputable. They are made to provide a base case scenario and serve as a source for later variations.

An Infantry agent represents an infantry man’s capabilities. Infantry units do not have significant movement throughout the simulation. Tanks not only represent possible employment of the tank’s heavy machine gun, but all non-radar guided heavy machine guns, whether from a heavy gun company or an air defense unit. The assumption is made that a tank would not employ its main gun as a direct fire weapon on a UAV. The Tank unit’s mission is to take up a blocking position and is moving to the southeast in order to do so.

ADA units are modeled to represent both shoulder-launched Surface-to-Air missiles (SAMs), and smaller mobile radar-guided missile and anti-air weapon systems. The difficulty with trying to model such a range of capabilities is that the result does not quite look like any of them. The variations of range and Pk values do, however, cover this capability set appropriately. An ADA unit behaves in the following manner. Initially, the ADA moves to a shooting position. During any move, sensor ranges are relatively low and weapons are disabled. Once stopped, the unit’s weapons are enabled, sensor range is increased, and personal concealment is increased. When the agent takes a shot, it immediately moves to prevent being targeted by indirect fire, displacing to another firing position. If the UAV comes into sensor range during any movement, the ADA will stop and prepare to fire. State changes are used to model this move-shoot-move behavior.

Although Raffetto’s basic model build is used as a starting point, some modeling approaches had to be adjusted in order to accommodate the emphasis on survivability versus effectiveness. The behavior of the ADA described above is the first example. In addition, Raffetto had modeled the UAV detection of enemies and neutrals as the UAV “shooting” them once agents were classified, with a 100% Pk. This served as a convenient surrogate for detection for two important reasons. First, it provided a measure of performance by counting the number of enemy and neutral agents classified (i.e., killed). Second, it promoted proper behavior, as identified (shot) agents were removed from the UAV's SA map. This kept the UAV from lingering over these agents due to its attraction to enemy agents. It was not necessary for these agents to shoot at the UAV or to remain on the battlefield after detection because their only purpose was to give the UAV something to identify. Unfortunately, a reasonable survivability model requires that the enemy can shoot at the UAV both before and after their being identified.

To accomplish this, two vital aspects of the model are changed. First, weapons are given to all enemy agents. Second, all agents are made invisible to the UAV after it detects them. This is also implemented using the state change feature of MANA for enemy and neutral agents. The UAV still "shoots" at agents it identifies, but rather than dying, the identified agents change state. In this state, their concealment value is raised to 100% so that they become invisible to the UAV. This prevents the UAV from remaining over already identified agents and yet those agents can still shoot at the UAV. No other agent characteristics are altered in this "shot at" state, keeping the agent's behavior consistent in both states. The state change lasts for sufficient time for the UAV to leave the area. However, if it should pass by again later, those agents would again be visible to the UAV and be prosecuted by it.

This post-detection concealment is modeled differently for the ADA. Because of its use of state changes to model the desired behavior, mentioned earlier, a state change could not also be used as a before-and-after detection device. An agent may not be in two states at the same time, yet the desired behavior sets are not mutually exclusive. The ADA need to move-shoot-move both before and after being detected by the UAV. To overcome this, the agent that actually shoots at the UAV remains invisible at all times. A second "shadow" agent is added that stays exactly with the first. The UAV detects this shadow agent, which turns invisible for the appropriate duration, once detected (shot) by the UAV. In this way, both the ADA behavior and the UAV behavior remain appropriate and consistent.

Another major aspect that differs from the Raffetto model is the time increment. MANA is a time step simulation. As such, at each time step, or smallest discernible increment of time in the simulation, every agent senses, fires, moves, and communicates. The modeler determines the size of this time step. This, in turn, affects the level of aggregation. This means that if a 5 minute time step is used, agents need to exhibit appropriate behavior for a 5 minute time period in each time step. Therefore, movement rates, number of engagements, rates of fire, etc., must be adjusted proportionally. In this model, the time step size is changed from the 36 seconds of Raffetto's model to 3 seconds. This is done to model more appropriately the sensor capabilities of the enemy agents shooting at the UAV. At high UAV speeds, a 36 second time step would cause the UAV to travel a greater distance than the sensor range of the enemy agents. For example, if a UAV with a speed of 7 grids per time step approaches an agent with a 2 grid sensor radius, the UAV could be 2 grids in front of the agent's sensor range at one time step and then 1 grid beyond it on the next. Therefore, that agent does not have the opportunity to register the UAV's presence and, consequently, does not fire at it. Some early runs executed with a 36 second time step lead to a significant, if somewhat obvious, finding. You cannot shoot what you cannot sense. In this situation, survivability is exceptional and a strong case is made for stealth regardless of any other enemy or friendly parameter. With a change to a 3 second time step, the UAV cannot over-step any agent's sensor range at any of the speeds used. Speed can now be varied over the entire desired range of 60 to 400 knots.

Detectability is not as straightforward as speed to model. Detectability is the opposite of stealth. MANA has a parameter called "Stealth," or "concealment," which can be set for each agent. This concealment value determines the probability that an agent is seen by another agent given that it is otherwise visible. Visibility is determined by sensor range, line of sight, the terrain concealment value,* and the target agent's concealment value. MANA effectively evaluates visibility in that order, with each step conditional on the success of the previous step. For instance, an agent with a personal concealment value of 50, who is in open terrain and within another agent's sensor range,

* Each terrain type has an associated concealment value, similar to an agent's, that probabilistically determines a detection; i.e., open terrain has a concealment value of zero.

has a 50-50 chance of being seen by that agent, per time step. This is appropriate for a camouflage type of concealment, but it is not a complete idea of stealth. Stealth, for a UAV, also needs to include an element that will not allow detection at all outside of a given sensor range, dependent upon the strength of stealth. In order to model both these aspects of stealth, the UAV concealment value is varied from 0 to 100 and enemy sensor range is also varied from zero to the max range used for that weapon system.

The other factors that are varied are more direct in nature. Two UAV personality weightings are varied; the attraction to enemy (0-100) and the attraction to the next waypoint (10-100). These weightings in the movement algorithm represent tactical employment methodologies by characterizing the propensity of the UAV to stay precisely on the prescribed route versus moving toward high concentrations of enemy agents. In other words, should the UAV stay on its assigned routing or should it go toward known enemy locations in hopes of finding more. Note that the minimum weight for the next waypoint is ten, not zero. This ensures that there is an initial desire to move away from the ship. This confirms the theory that an unused UAV has perfect survivability.

MANA has the capability to first detect another agent and then classify what type of agent it is: enemy, neutral, or friend. Each of these processes can have different ranges at which they occur and can be deterministic or probabilistic. Initial intentions for this model were that the detection range would be larger than the classification range and that both would be deterministic. This would allow an attraction to unknown agents to be incorporated and varied without getting into sensor efficiency issues. However, a sensor modeled in this way occasionally displays irregular behavior. Specifically, the UAV would sometimes remain hovering over an unknown detection for long periods. This has two ill effects, one of inordinate exposure to close range enemy fire, thereby decreasing survivability, the other effect being that of not covering the intended route before the simulation times out at 33 hours equivalent time. To avoid this behavior, the UAV employs a cookie-cutter sensor so that any agent sensed is simultaneously identified. An attraction to unknowns is then of no effect as there are no unknowns. This factor is removed from all variations of the base case.

Enemy factors are varied to gain results that are more robust. These include both enemy sensor ranges and Pk values. Infantry and Tank Pk values are set to be decreasing with range in a straight line approximation to curves of actual values. ADA Pk values are uniform over their effective ranges. The variation of both sensor range and Pk represent the varied capabilities of both current and possible future systems. Anticipated future capabilities are intentionally exceeded to ensure a valuable solution set, even if enemy capabilities surpass technological expectations. This follows the planning mantra never to base a war plan solely on an expected course of action. You must consider the most dangerous along with the most likely possibilities. The variation of enemy sensor ranges also represents a portion of the UAV's stealth capabilities. Viewed in this way, it is a characteristic that can be controlled in design. Viewed as an enemy capability, it is uncontrollable.

In summary, both UAV and enemy characteristics are varied to discover their effect on survivability. UAV characteristics include speed, stealth, sensor range, and personality weightings toward enemy and next waypoint. Enemy characteristics are sensor range and Pk values. Table 1 gives the values over which these factors are varied in both real world units and equivalent MANA unit values. MANA unit values are determined by the size of the area modeled, the size of a grid overlay on that area, and the time step chosen. Here the 150 nm square area is overlaid with a 1000 by 1000 grid matrix. Each grid, then, represents approximately 295 meters square. The time step is 3 seconds. See Appendix C for conversion tables for standard and MANA units.

Input values for sensor and weapon ranges, weapon Pk values and speeds are based upon open source data, such as "Jane's All the World's Aircraft" (**REFERENCE**), the Federation of American Scientists website (www.fas.org), and various Contractor and government program websites for both current and predicted systems. As each of these is a varied factor in the simulation, the values used are an expansion around these base values. This captures the range of capabilities from a poorly trained and poorly equipped force up to a well equipped and trained force. Possible scenarios this is intended to simulate are from poorly equipped and trained splinter government or insurgent forces all the way to a Northeast Asian scenario. Classified values from the Army Materiel

Systems Analysis Activity (AMSAA) were verified to lie within the Base case value ranges.

	Base Scenario		Accelerated Life Test Values	
Factors	Real world ranges	MANA units	Real world ranges	Expanded values
UAV				
*Stealth	0 - 100%	0 – 100		
*Sensor range	0.9 – 14.8 km	3-50 grids		
*Speed	47.8 – 350 knts	25 – 183 grids per time-step	47.8 – 400kts	25-209 grids per time-step
*Enemy weight	n/a	0 – 100		
*Next Waypoint weight	n/a	10 – 100		
Tanks				
*Pk pt 1 (to 295m)	0.0005-0.0100	5-100	0.0005-0.0300	5-300
Pk pt 2(to 590m)	0.0001-0.0030	1 – 30	0.0001-0.0090	1-90
Pkpt3(to 1772m)	0.0001-0.0010	1-10	0.0001-0.0030	1-30
*Sensor range	0 – 2.95 km	0 – 10 grids	0 – 8.86 km	0-30 grids
ADA				
*Pk	0.0010 - 0.0500	10-500	2.95–442.9km	10-1500
Sensor range (moving)	0 – 5.32 km	0-18 grids	0 – 15.95km	0-54 grids
*Sensor range (stationary)	0 – 7.97 km	0-27 grids	0 – 23.92km	0-81 grids
Infantry				
*Pk pt 1 (to 590m)	0.0001- 0.0001	1-10	0.0001-0.0030	1-30
Pk pt 2(to 1181m	0.0001-0.0005	1-5	0.0001-0.0015	1-15
*Sensor range	0- 1.772km	0-6 grids	0 – 5.32km	0-18 grids

* included in NOLH design

Table 1. Factors Varied with Real-World Values and MANA Unit for Base Case and Accelerated Life Scenarios.

The NOLH design creates 65 levels of each of the 12 continuous factors asterisked in Table 1. A complete list of the design point values used in the simulation runs appears in Appendix A. In order to maintain appropriate capabilities within a design point, some factors must not be varied independently. Those factors are not included in the NOLH design but are varied directly with other values that are in the design. The short range and long range Infantry Pk points serve as an example. If the two points of Infantry Pk were both included in the NOLH design, there would be runs executed where Infantry weapons were more accurate at long range than at short range. Likewise, there would be disparity between similar squad types as one Infantry squad may be more effective than another, if each Infantry squad were included in the NOLH design. The desire is to vary the overall capabilities of each type of unit synchronously and consistently. This is achieved through varying Pk values within a squad together and across squads together.

Each of the 65 design points are replicated 100 times in order to obtain a distribution of outcomes around a single design point. The measure of effectiveness is the percentage of time the UAV survives over the 100 replications at each design point. Average survivability across the design points is over 97% in the base case. This is the expected order of magnitude for a realistic scenario and validates the modeling effort to some extent. However, with such high survivability rates, it is very difficult to discern the effects of the varied factors.

At these rates, almost any improving effect will raise survivability to 100%, leaving little room to distinguish a good improvement from a better improvement. To increase sensitivity to the effects of the varied factors, the ranges of both enemy Pk values and sensor ranges were tripled. This is the simulation equivalent of Accelerated Life Testing, where environmental conditions are manipulated on physical systems in order to accelerate degradation and determine life expectancy or failure rates. Here, a more lethal environment is created to gain sensitivity to varied inputs. The Accelerated Life values are applied to the base case scenario and are listed in Table 1. They are also the only values used in the eight additional variations explained in the next section.

B. VARIATIONS

The variations to the base case are divided into three groups; altitude, tactical layout, and density. Each group contains three levels. As mentioned earlier, the variations are created to ensure that results are not highly sensitive to model inputs. They also allow for trade-offs to be more thoroughly explored. They are not included in the NOLH design because the design is more efficient with a higher number of levels. There are too few factor levels in these variations to get appropriate orthogonality in the design, and low correlation is compromised. Other technical issues with the run set up also made this impractical given the time constraints. The variations are therefore blocked on top of the NOLH design such that each variation has the complete NOLH design contained within.

1. Altitude

Altitude clearly aids survivability. The higher a UAV flies, the fewer weapons can shoot it. High altitude UAVs, however, tend to be large in both size and expense, requiring larger engines and higher fidelity sensor equipment. Varying altitude over the range of base factors allows the assessment of how important altitude is and what other areas may improve survivability given particular altitude restrictions due to size or cost.

Unfortunately, MANA has no inherent altitude capability. Elevation of the ground can be modeled, but altitude above the ground cannot be. Therefore, in each of these altitude variation cases, the weapon ranges for effective systems are adjusted using a slant range projection. The three-dimensional slant range is projected down onto the two-dimensional battle space. See Figure 6, page 18, for an illustration of this technique.

The base case models a 1000' AGL altitude. This altitude allows weapons down to high powered small arms to range the UAV. Weapon ranges are not adjusted for slant range at this altitude due to its minimal effect. The only change for this run then is the Accelerated Life values. The other two altitude variations are modeled at 5,000' and 10,000' AGL, representing the points where small arms become ineffective and where heavy guns become ineffective, respectively. These two cases apply the effective range reduction for the remaining effective weapon systems.

2. Tactical Layout

The variation in tactical layout is executed so that resulting survivability rates are not dependent on a particular layout of forces and the timing of UAV passage of an area. This second issue is most important concerning the ADA, which have restricted firing capability while moving. CPT Chuck Sulewski, a US Army Operations Research student at NPS with an artillery background, created the alternate tactical layout designs at the Project Albert International Workshop X (PAIW X). CPT Sulewski, who was unfamiliar with the project and the Sea Viking scenario at the time, was asked "How would you employ these forces?" given the terrain, objectives, and forces available. The layouts that he came up with were not radically different from the original, but deviated sufficiently to provide the requisite amount of variation.

Each variation in this group builds on the previous one. The first variation is putting two ADA along the coast for early warning and interdiction. The third ADA is kept closer to the objective area as a close-in defense. The second variation assigns a mobile Avenger-like ADA to the tank unit. This ADA has the same sensor range moving as it does in its fixed firing position, unlike the standard ADA that have a reduced sensor range while in transit. The third variation splits the mountain forces in the east to cover both sides of the pass leading to the objective area.

3. Threat Level

Threat level is varied to ensure results are explored over a wide numerical range of enemy forces. Obviously, survivability rates will go down when the number of enemy agents goes up, due to increased exposure. The objective of this variation group is to find how or if the relative importance of the controllable factors changes in the presence of a more concentrated or numerous threat. Capt Sim Wee Chung of the Singapore Navy was the principal designer of these variations at PAIW X.

The variations in threat level are very straightforward from a modeling perspective. The first is simply three times the threat density. That is, within the same areas covered previously, there are now three times the number of agents present. This effectively un-does the original three-to-one aggregation. The other two variations in this group are two and three times the number of enemy agents, respectively. However, in these scenarios the agents are more spread out over the battle space. These higher threat level variations are intended to capture the differences in deployment environment from the insurgent type force of Sea Viking to a larger, more traditional force, as in a Northeast Asia type of scenario.

Within each of the nine variations, the same factors are varied according to the NOLH design. All ten scenario submissions were executed at the Maui High Performance Computer Center. Each submission has 65 design points, with 100 replications at each point. This yields 65,000 data points over the ten variations. To put this in perspective, a full factorial design with 12 factors and 65 levels of each factor would require 65^{12}, or 5.688×10^{21}, simulation runs. The efficiency of the design is clear. The design also provides the necessary data to perform extensive analysis. The analysis techniques are the focus of the next chapter.

IV. ANALYSIS TECHNIQUES

This chapter opens with a discussion of the post-processing of the output data. Next, the various methods used in analyzing the output data are presented. Examples are given of each analysis tool, using data from the simulation output. Each technique is briefly explained with emphasis on the insights gained. The references cited in each section provide more detailed information on these techniques. In the following chapter, analytical results from each scenario are discussed.

A. OUTPUT DATA

Through their focus on Data Farming, Project Albert has created many valuable tools for both generating and analyzing the vast amounts of data required of this methodology. The Tiller is a set up tool that allows large designs of experiment to be submitted to the computer cluster without the need for a human interface to load each individual run. This eXtensible Mark-up Language (XML) tool allows the user to select the factors to vary and the levels of each factor. Several design of experiment options are available including full and fractional factorials, and Nearly Orthogonal and Random Latin Hypercubes. Using the Tiller on each of the ten scenarios, ten separate runs were submitted to the Maui High Performance Computer Center (MHPCC) for execution.

The data generated from the MHPCC for each scenario submission is returned in comma separated value (.CSV) or Microsoft Data Base (.MDB) file format. Data of interest includes: excursion and random index numbers, values of each parameter at each design point, and the number of UAVs killed in each replication. Each excursion is a design point; the random index is the replication within the design point. The values of the varied parameters are from the NOLH design. UAVs killed has a value of zero or one. The CSV files are imported into JMP IN, a statistical analysis software package produced by SAS Institute. This software is utilized due to its data pre-processing capabilities, depth and breadth of available analytical tools, and its well designed, easy to use graphical user interface. Once the data are imported, it is summarized over each excursion, or design point, returning the mean UAVs killed for that excursion. Only the values for each parameter that was included in the NOLH design is retained in this summary, as the other values are 100% correlated and therefore provide no additional analytical information. Finally, two columns are added: Survival Rate, which is one minus mean UAVs killed; and Variation as the categorical label for the scenario variation. Survival Rate is the single Measure of Effectiveness.

The analysis is done primarily using Stepwise Multiple Linear Regression and Regression/Classification Trees. Each of these methods is explained in the next two sections. In the following chapter, each of the ten variations is analyzed together with their respective groups followed by an aggregate analysis across the variations.

B. MULTIPLE LINEAR REGRESSION USING STEPWISE SELECTION

Multiple Linear Regression (MLR) is a common method of determining factor effects on a response variable. Linear combinations of factors are fit to minimize the residual error, thereby yielding a "best fit" to the data. The Stepwise selection process begins with a pool of 88 possible terms consisting of all 11 main effects, all 11 squared terms and all 66 two-way interaction terms. Using an iterative process, terms are added to or removed from the model at each step based on a significance level of $\alpha = 0.05$. When there are no more terms eligible for addition or removal, the terms selected are fit in a linear regression. For more information on Multiple Linear Regression and Stepwise Selection, see Montgomery (2001).

Although MLR gives coefficient estimates for each significant factor, the focus here is on the relative importance of each factor and not the value of the coefficient. The response is a probability and is therefore limited to values between zero and one. The coefficient values are extremely small and difficult to interpret. However, the relative importance can be seen in the strength of significance of the coefficient. This is evidenced in the F statistic generated by the Linear Regression. A large F-statistic gives stronger indication that the coefficient is not zero. Because the factor variables are all of the same order of magnitude, the F-statistic can be viewed as a level of significance. In other words, it indicates which factors have the greatest impact on the survivability rate.

MLR assumes that the residual errors, i.e., the variation of the actual data from the predicted model values, are normally distributed. By using averages over the 100 replications at each design point, the Central Limit Theorem guarantees that the data will approach normality, except when the survival rate is near zero or one (Devore, 2004).

Normality is still not completely satisfied however, as probabilities can only take on values between zero and one, eliminating the tails of the distribution. Therefore, there are no positive residuals when the predicted value is one. Similarly, there are no positive residuals greater than 0.02 when the prediction is 0.98. Figure 7 shows this effect in the residuals plot. The plot on the left appears capped on the right side of the plot by a 45 degree boundary passing through the point (1.00, 0.00). The plot on the right shows residuals typical of all the accelerated value scenarios.

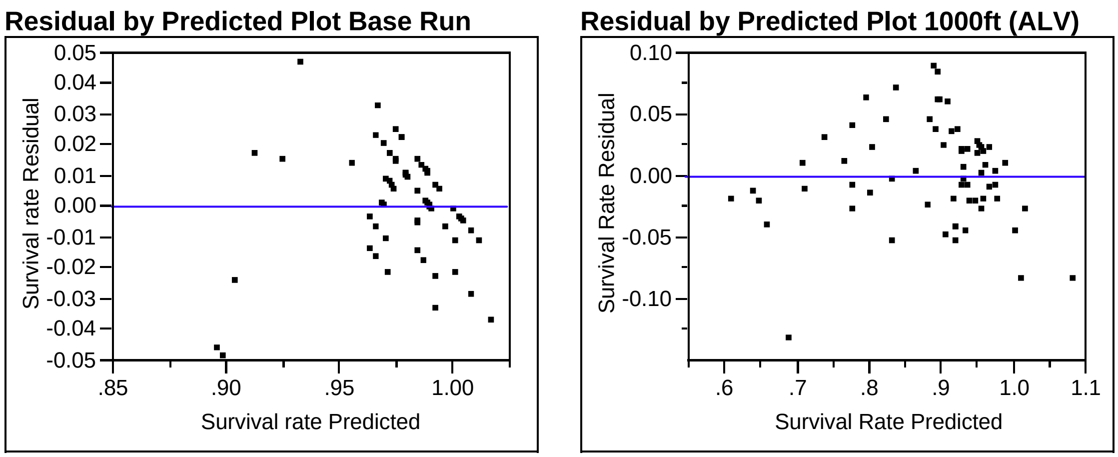


Figure 7. Residual versus Predicted Values Plot. Note the truncation at the right side of the plots where the sum of the predicted and residual can not exceed unity. Striation in the Base Run on the right is attributable to the plot fidelity as actual values only have two decimal places.

Linear Regression also assumes homoscedastisity in the residuals. Many of the residual plots show clear evidence against this constant variance assumption. Yet the Linear Regression still yields valid results, even with the violation of these assumptions. Here is why: all these assumptions primarily affect the t and F-probabilities. These, in turn, affect the confidence level with which each factor can be judged significant. With the very high confidence in significance levels shown across all scenario models, the violation of these assumptions has no qualitative effect on the results. Additionally, because the focus is on relative significance, theses violations are again of negligible impact.

Figure 8 highlights several items of the MLR output. The Actual by Predicted plot at the top visually displays the accuracy of the regression fit. Vertical distance from the straight line fit indicates the deviation of the actual data values from those predicted by the regression model. Notice the dense grouping of the majority of data points in the upper right corner in contrast to the few points outside the group. These few points drive the model fit. This is appropriate here as these design points all have both low speed and stealth values that combine to produce lower survivability.

The R-square value in this model is 0.67. R-square is a measure of the variability explained by the regression model. This relatively high R-square value is achieved even though there are only seven significant terms. Partly, this is due to all but one having confidence levels of over 99%. There is no doubt of their belonging in the model, even considering the lack of normality in the residuals.

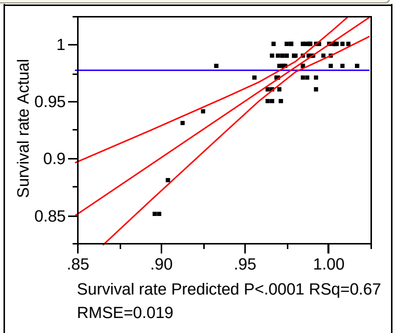
The F Ratio, under the heading Effect Test, gives a basis for comparison of relative importance of significant factors. Speed and Stealth are effectively equal in this regard in Figure 8. Compare this to Figure 9, which shows the MLR output for the 1,000ft Accelerated Value run. Speed dominates all other factors by an order of magnitude. This demonstrates the utility of the accelerated values. By modeling a more deadly environment, the difference in the advantage gained by Speed over Stealth can be readily distinguished.

Despite the low sensitivity of the Base model, some interesting interactions are still indicated. UAV Speed has a positive interaction with both ADA Sensor Range and ADA Pk. The positive value shown under the Parameter Estimates heading indicates that increased speed mitigates the advantage of the enemy's increased capabilities. The last item under the same heading, the UAV Speed squared term, has a negative value. This indicates that at some point, the rate of increase in survivability due to increasing speed begins to taper off. Although not definitive, these items are things to watch for in the accelerated models.

Finally, Figure 10 shows a plot of the F-Ratio for each factor. This is a good visual representation of the relative significance of each factor. The "knee" in the curve represents the point of diminishing returns in terms of overall model significance for each significant factor.

Whole Model Base Run

Actual by Predicted Plot



Summary of Fit

RSquare	0.66612
RSquare Adj	0.625117
Root Mean Square Error	0.018988
Mean of Response	0.977692
Observations (or Sum Wgts)	65

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	7	0.04100223	0.005857	16.2457
Error	57	0.02055162	0.000361	Prob > F
C. Total	64	0.06155385		<.0001

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.9555887	0.009456	101.05	<.0001
UAV Stealth	0.0004527	0.00008	5.63	<.0001
UAV speed	0.0002748	0.000051	5.39	<.0001
ADA2 sns rng st4	-0.000923	0.000297	-3.10	0.0030
ADA2 Pk st4	-0.000038	0.000016	-2.30	0.0250
(UAV speed-103.769)*(ADA2 sns rng st4-13.0154)	0.0000299	0.000007	4.24	<.0001
(UAV speed-103.769)*(ADA2 Pk st4-254.523)	9.2446e-7	3.862e-7	2.39	0.0200
(UAV speed-103.769)*(UAV speed-103.769)	-0.000003	0.000001	-2.62	0.0112

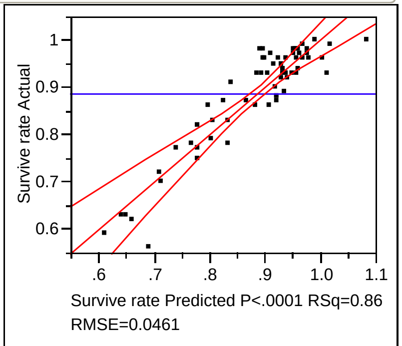
Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
UAV Stealth	1	1	0.01144364	31.7390	<.0001
UAV speed	1	1	0.01048207	29.0721	<.0001
ADA2 sns rng st4	1	1	0.00347260	9.6313	0.0030
ADA2 Pk st4	1	1	0.00190968	5.2965	0.0250
UAV speed*ADA2 sns rng st4	1	1	0.00647320	17.9535	<.0001
UAV speed*ADA2 Pk st4	1	1	0.00206565	5.7291	0.0200
UAV speed*UAV speed	1	1	0.00247650	6.8686	0.0112

Figure 8. Regression Analysis For Base Run 1000 Ft Altitude Without Accelerated Threat Values.

Response Survive rate 1000ft Accelerated Values

Actual by Predicted Plot



Summary of Fit

RSquare	0.861132
RSquare Adj	0.822249
Root Mean Square Error	0.046144
Mean of Response	0.886615
Observations (or Sum Wgts)	65

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	14	0.66019172	0.047157	22.1468
Error	50	0.10646366	0.002129	Prob > F
C. Total	64	0.76665538		<.0001

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.8805006	0.029963	29.39	<.0001
UAV Stealth	0.0004936	0.000195	2.53	0.0147
UAV enemy	-0.000064	0.000195	-0.33	0.7428
UAV sns rng	0.0012426	0.000415	3.00	0.0043
UAV speed	0.001189	0.000106	11.20	<.0001
Tank Pk pt1 st1	-0.000315	0.000066	-4.75	<.0001
Tank sns rng st1	-0.001448	0.000648	-2.23	0.0300
ADA_1_ sns rng st4	-0.001502	0.000241	-6.23	<.0001
ADA_1_ Pk st4	-0.000076	0.000013	-5.78	<.0001
(UAV enemy-50.0308)*(UAV speed-117.062)	-0.000014	0.000005	-3.19	0.0024
(UAV sns rng-26.5077)*(Tank sns rng st1-15.0154)	-0.000263	0.000054	-4.85	<.0001
(UAV speed-117.062)*(Tank Pk pt1 st1-152.508)	0.000003	0.000001	2.35	0.0229
(UAV speed-117.062)*(ADA_1_ sns rng st4-40.5077)	0.0000152	0.000005	3.20	0.0024
(Tank Pk pt1 st1-152.508)*(ADA_1_ sns rng st4-40.5077)	-0.000009	0.000004	-2.53	0.0147
(ADA_1_ sns rng st4-40.5077)*(ADA_1_ Pk st4-755.015)	-0.000003	6.575e-7	-5.06	<.0001

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
UAV Stealth	1	1	0.01358922	6.3821	0.0147
UAV enemy	1	1	0.00023192	0.1089	0.7428
UAV sns rng	1	1	0.01910690	8.9734	0.0043
UAV speed	1	1	0.26717570	125.4774	<.0001
Tank Pk pt1 st1	1	1	0.04809503	22.5875	<.0001
Tank sns rng st1	1	1	0.01062432	4.9896	0.0300
ADA_1_ sns rng st4	1	1	0.08257426	38.7805	<.0001
ADA_1_ Pk st4	1	1	0.07113918	33.4101	<.0001
UAV enemy*UAV speed	1	1	0.02169529	10.1891	0.0024
UAV sns rng*Tank sns rng st1	1	1	0.05011618	23.5368	<.0001
UAV speed*Tank Pk pt1 st1	1	1	0.01173715	5.5123	0.0229
UAV speed*ADA_1_ sns rng st4	1	1	0.02186492	10.2687	0.0024
Tank Pk pt1 st1*ADA_1_ sns rng st4	1	1	0.01358824	6.3816	0.0147
ADA_1_ sns rng st4*ADA_1_ Pk st4	1	1	0.05458773	25.6368	<.0001

Figure 9. Regression Analysis for 1,000 Ft Altitude with Accelerated Threat Values. Note the greater range of data on the plot at top as well as increased sensitivity evidenced in the higher R-square value and greater number of significant factors.

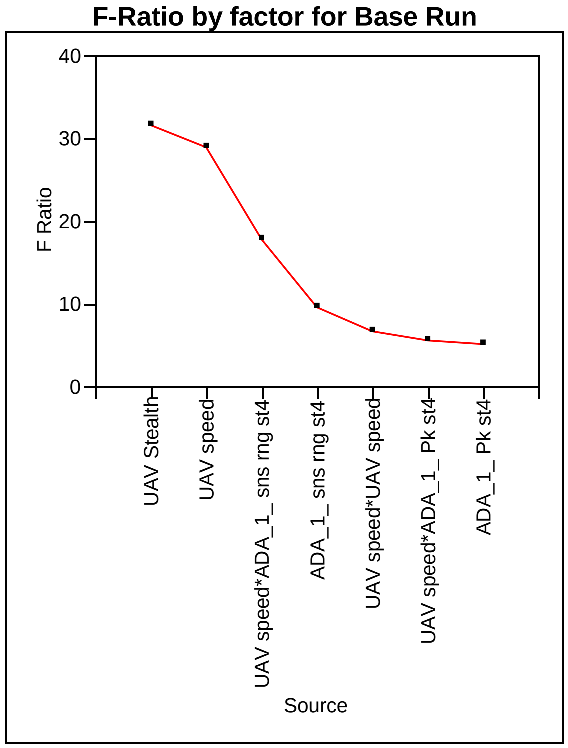


Figure 10. Plot of F-Ratio of Linear Regression Effect Test for Base Run.

C. REGRESSION TREES

Regression Trees are an excellent technique that combines analysis and display in an easily understood format. (Whitaker, 2005) The central idea of this method is simply to divide the data into two groups. The criterion for making the split is to find the one level of the single factor that creates the greatest difference in mean response between the two groups. Dividing the data in such a fashion identifies both the most important factor and its most significant level. Iterating this process on the remaining groups create subsequent splits. This produces both sequentially significant factors and important interactions. Displayed as a tree graph, the results are easy to interpret. Figure 11 shows the Regression Tree for the 3X Threat Density Scenario.

Speed is the first break point of this model. The Tree shows a mean survival rate of only 40.5% with speeds below 135 knts and 75.5% when above that mark. The second level breaks are conditional on the first. Looking down the left branch, i.e., given a speed of less than 135 knts, ADA Sensor Range is the most significant factor at a level of 35 (grids)*. Going down the right branch, ADA Pk at a level of 0.1104 (per shot per time-step), is the most significant, given a speed of greater than 135 knts.

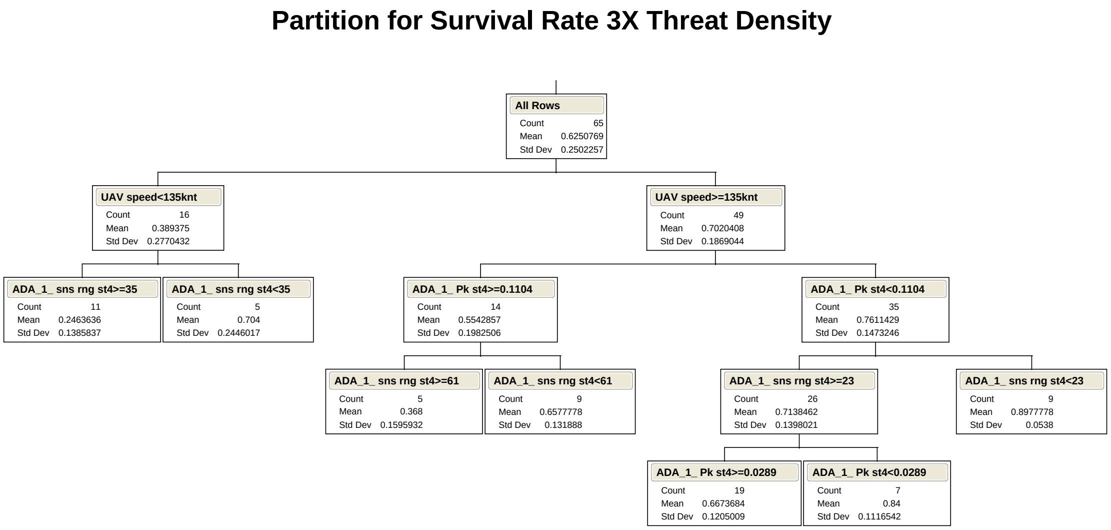


Figure 11. Regression Tree for 3X Threat Density Scenario.

Regression trees do not assume a particular distribution of the data, are robust to outliers, and inherently display interactions. However, there are some draw backs to Regression Trees. There is no sense of the relative importance of the factors in the tree other than the hierarchical nature of the tree structure. For example, in Figure 11, Speed is more important than ADA Sensor Range, but how much more important? Neither is there a sense of how close a decision the split was. Speed of more than 135 knts is the best split point, but how much is lost by splitting at 130 knts? Is 135 knts a vast or marginal improvement over 140 knts? The break points also tend to be somewhat unstable, especially as the groups become small. For these reasons, Regression Trees are used here in conjunction with results from other techniques, such as Linear Regression.

D. LOGISTIC REGRESSION

Logistic Regression provides a method of analyzing the raw success-failure output data without having to justify violating the assumptions of normality made in Linear Regression. Details on Logistic Regression can be found in Montgomery, Peck

* The real world unit of measure is intentionally omitted due to the stretching of the ranges from the Accelerated Life Values.

and Vining (2001). Though Logistic Regression asks a somewhat different question with its focus on the odds of success, the results are comparable to the linear regression of the survivability rates. In order to give complete support of the analytical effort, Logistic Regression is applied to all data sets. The results back those of the Linear Regression. They are not discussed here for brevity, but are included in Appendix B with the other analysis data.

E. PLOTS

Several different types of plots are generated in the analysis as data visualization aids. They help in understanding the main factor effects as well as interactions between factors. Selected plots are shown in the analysis to highlight important findings. More plots are contained in Appendix B.

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V. CONCLUSIONS AND RECOMMENDATIONS

This chapter looks at the analysis of each scenario using the techniques discussed in the previous chapter. While many factors are found to have statistical significance, the focus is only on those items of militarily practical significance. The complete raw analytical results are found in Appendix B.

A. SCENARIO VARIATION ANALYSIS

There are ten distinct scenario variations divided into four groups: the base case, three altitude variations, three tactical layout variations, and three threat level variations. The base case has the most realistic Pks and sensor ranges and is modeled at a 1,000ft altitude. The altitude variations include scenarios modeled at 1,000ft, 5,000ft, and 10,000ft altitudes. Three tactical layout variations implement changes in the geographic placement of enemy forces. The threat level variations model two and three times the number of enemy with proportionally larger starting areas and a triple density containing three times the number of enemy restricted to the same size area as the base case scenario. To increase sensitivity, all scenarios are executed with the accelerated life values, except the base case. Each variation contains the full NOLH design of varied factors in addition to the scenario change.

1. Base Case Analysis

Figure 12 shows a histogram of the survivability rates across the design space of the base case. The height of each bar indicates the number of excursions with that survivability rate. The number of survivals over the 100 replications determines the rates and is therefore a discrete two decimal value. Notice that the majority of the observations are bunched up near 1.0 and the small number of observations below 95%. The Box-and-Whiskers plot above the Histogram is a visual representation of the dispersion of the data. The rectangular box at right contains the middle 50% of the observations, known as the interquartile range. Inside the box, the vertical line indicates the median value and the diamond indicates a 95% confidence interval around the mean. The horizontal line, or whisker, shows a distance one and one half times the interquartile range from the edge of the box. The single points to the far left are outlier observations that fall beyond the whiskers. The bar under the box shows the position of the shortest, or most dense, 50% of the observations (Sall, 2005).

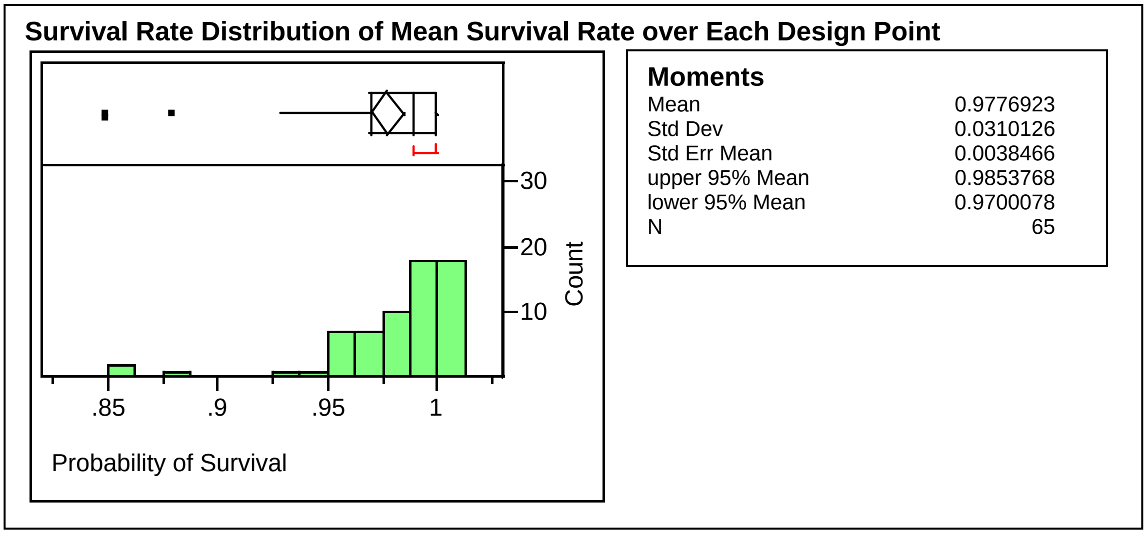


Figure 12. Histogram of Survival Rate over Each Design Point of the Base Case.

The overall mean survival rate, shown at right in Figure 12, is 97.7%. This is a realistic value for the given scenario and validates the model to some extent. This high value, though appropriate, does not provide adequate sensitivity to the varied factors. In other words, with the average so high any improvement will yield perfect survivability. This does not allow for distinguishing a good improvement from a better improvement. This is the motivation behind the Accelerated Life values used in the balance of the scenarios. Like operating a machine continuously in adverse conditions, artificially high enemy sensor ranges and Pk values are expanded to create a more deadly environment.

There are four main effects and three interactions selected from the pool of 88 possible terms in the Stepwise MLR model. These seven terms explain 67% of the variability of the model, based on the R-square value. As mentioned earlier, Speed and Stealth are virtually tied as the most significant terms in this model. The next most significant term is the interaction between UAV Speed and ADA Sensor Range discussed earlier. The positive value of this term indicates that increases in speed can diminish the increased effectiveness of larger ADA Sensor Ranges. The contour plot in Figure 13 shows the effect of this interaction. The area in the upper left corner of the plot has the lowest survivability. As Speed increases form 25 to 75 MANA units, (about 60 to 140 knts) the low survivability area is quickly escaped and the survivability becomes nearly homogeneous.

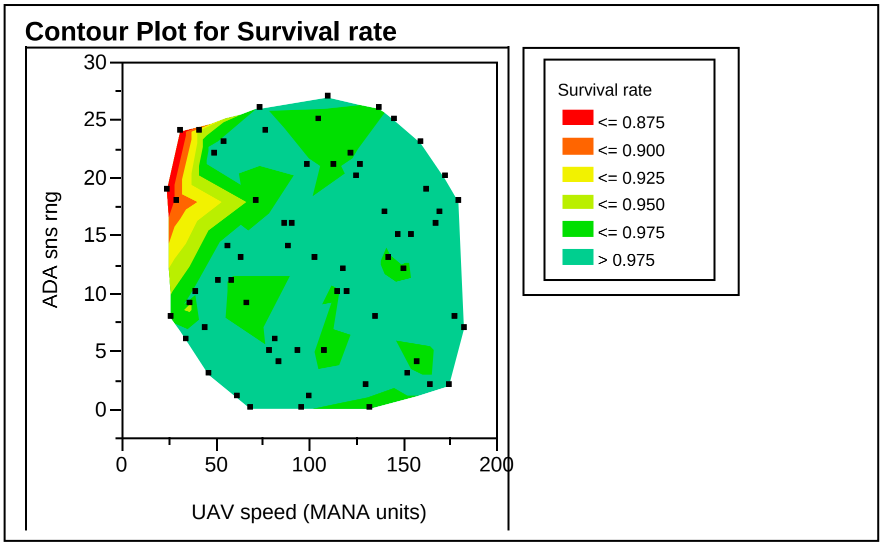


Figure 13. Contour Plot Showing Interaction between UAV Speed and ADA Sensor Range. (Best viewed in color)

The Regression Tree for this scenario is shown in Figure 14. It supports the analysis of the MLR, breaking first at Speed and then at Stealth. The significance of the terms below this point is questionable because of the small difference in means. The break point chosen is simply the best of a number of poor choices. Note the Speed break point is in MANA speed units of grids per 100 time steps. This is done here, as in other places throughout the remainder of this chapter, because the specific speeds generated should not be taken as significant apart from other analysis. A conversion table is included in Appendix C.

The accelerated life values for enemy Pks and sensor ranges are applied to the Base Case without any other modifications. Figure 15 shows the notable difference in the distribution of results. The mean survivability rate has dropped to 88.7%, the lowest observation is 55%, and there is only one observation that is 100% survivable. This dispersion of observations provides the room needed to see distinguishable effects of individual factors. The MLR identifies 14 significant factors at greater than 95% confidence in this case. This includes eight main effects and six interaction terms, with an exceptional R-square of 0.86 for the model.

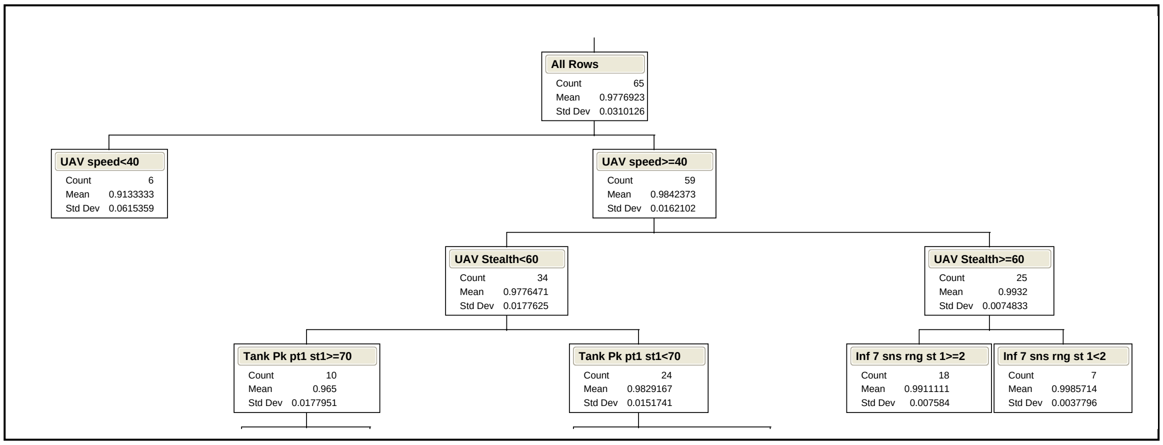


Figure 14. Regression Tree for the Base Case. Shows Speed and Stealth as the first two break points.

Speed dominates this scenario as the most significant factor. This is the case despite the fact that the 100% survivable observation is so because of a 100% stealth value. This emphasizes the point that 100% Stealth yields perfect survivability, but if that degree of stealth is not attainable Speed does much more to increase survivability in this scenario.

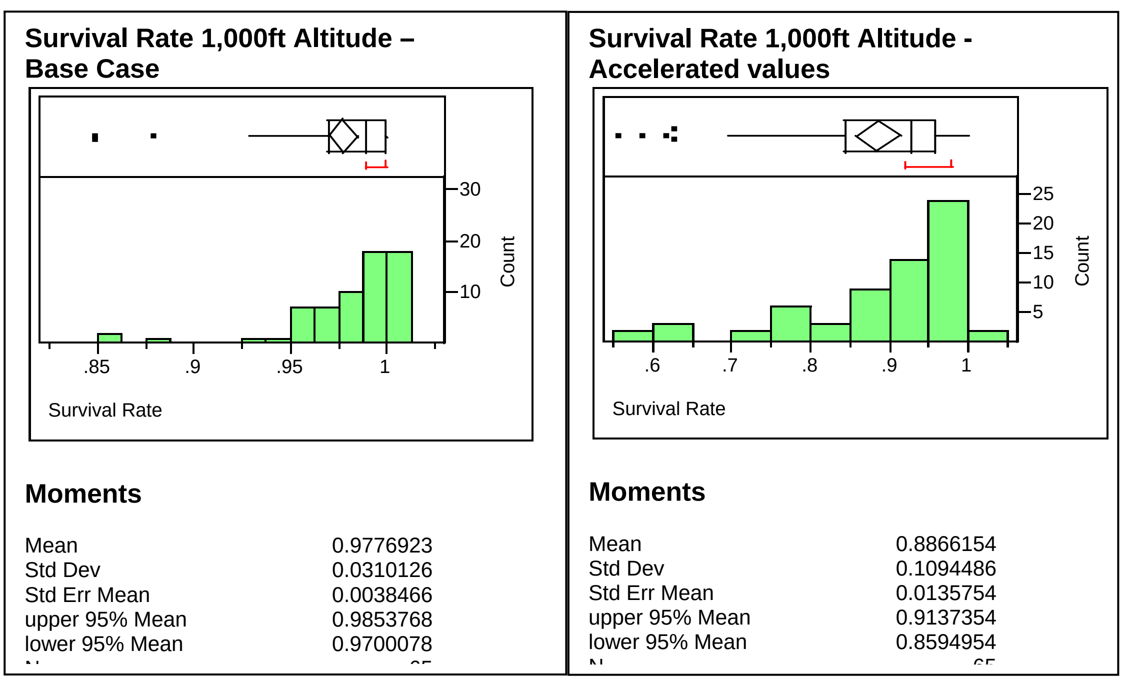


Figure 15. Survival Rate Distributions for Base Case and Accelerated Life Values at 1,000ft Altitude.

ADA Sensor Range, a form of stealth, ranks second in significance. ADA Pk, followed closely by the interaction between these two enemy capabilities, rank third and fourth. This interaction indicates a synergy between these capabilities that yields higher lethality than the increases expected singularly. UAV Speed interacts with both Tank Pk and ADA Sensor Range. This indicates a tendency for Speed to mitigate the expected increased effectiveness of increased enemy capabilities. A negative coefficient on the interaction between Speed and the UAVs attraction to enemy agents shows a decrease in survivability as the values increase together. Because the attraction only has influence over the UAV when there is a large concentration of enemy present, the increased speed hurries the UAV into the teeth of the enemy's forces.

The Logistic Regression supports the MLR, as it does in each of the succeeding cases as well. In general, it will not be addressed in the text, but is available in Appendix B. However, the increased sensitivity of the Logistic Regression best illustrates the amount that each term adds to the model. Figure 16 shows that the first five terms contribute the most to this model as the successive terms contribute a smaller and smaller percentage. A Linear Regression based on only the top five terms, plus two main effects of interactions not otherwise selected, yields an R-square of 70% versus the 86% of the full 15 term model. This differential is even more pronounced in the other scenarios. Therefore, only the top four or five terms are discussed in the following analytical sections.

The Regression Tree also shows the dominance of speed in this scenario, with a break point of approximately 135 knts. Second level splits are on tank and enemy Pk values for both low and high speed branches, respectively. Again, this is an indication that Speed lessens the effectiveness of increased enemy capability. Stealth*, that is MANA's camouflage type of stealth, is not found to be a determining factor in the tree, emphasizing Speed's dominance.

* In the text, capitalized Stealth will refer to MANA camouflage type Stealth. Lower case stealth will refer to stealth in its totality or range reduction stealth, the distinction being made clear in context.

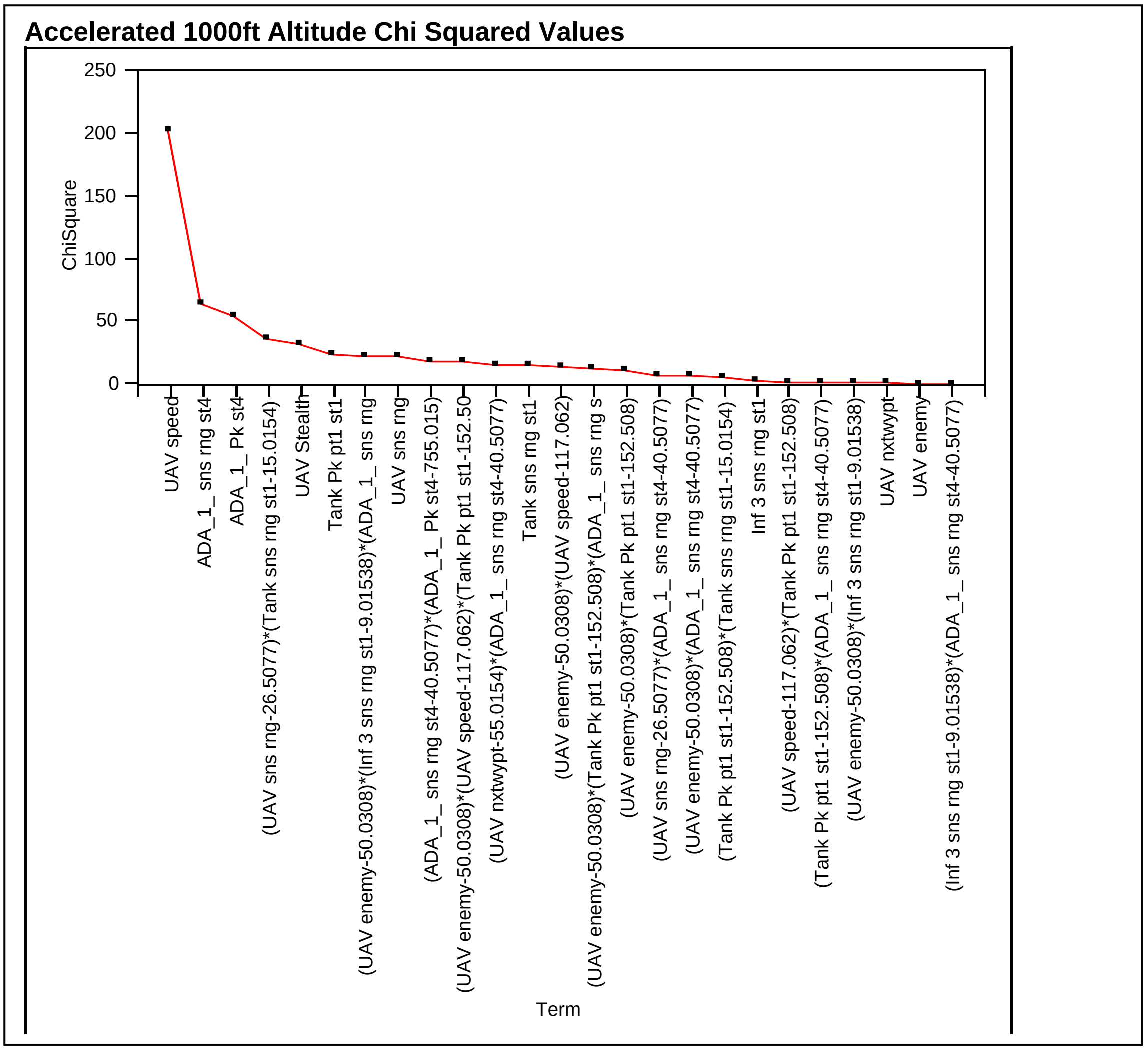


Figure 16. Chi Square Values for Accelerated 1,000ft Altitude. Shows relative significance of terms in the Logistic Regression model.

2. Altitude Analysis

The three variations are based on 1,000ft, 5,000ft, and 10,000ft altitudes. The intent in selecting these altitude values is to capture representative points at which a particular class of enemy weapons will no longer be able to range the UAV. At 5,000ft, the Infantry weapons become ineffective. At 10,000ft, the Tank weapons, representing all heavy machine gun assets, become ineffective. For the weapons that remain effective, their sensor ranges are adjusted for slant range, causing an effective range reduction, as described in Chapter III. The 1,000ft case is the one just discussed as the first of the accelerated life value variations.

In general, higher altitudes yield higher survivability. It also markedly decreases the variability across the design points. The 5,000ft and 10,000ft cases have only seven and eight significant terms, respectively, in the MLR. This is in contrast to the fourteen terms at 1,000ft. However, the 5,000ft case has the same top three significant factors as the 1,000ft case. These same three terms, Speed, ADA Sensor Range, and ADA Pk, are in the top four at 10,000ft with the top two being the same.

Speed is again at the top at 5,000ft, although not by so great a margin. This trend continues in the 10,000ft case as Speed and ADA Sensor Range become virtually tied. The two interaction terms, UAV Speed with ADA Sensor Range and ADA Sensor Range with ADA Pk, are also common to all three altitude cases. It is the former that moves up to number three in the 10,000ft case. This, taken with the addition of a Speed squared term, emphasizes the value of speed even though ADA Sensor Range is the single most influential main effect.

The CRT shows Speed at the top of each altitude scenario. See Appendix B for this and other tables and charts not shown in the text. The break point is 135 knts in both the 1,000 and 5,000ft cases. It lowers to 118 knts at the 10,000 ft, indicating the slightly decreasing importance of higher speed at that altitude. The second level breaks at some type of enemy capability in all but one branch. At 1,000ft, both low speed and high speed branches break on enemy Pk values for Tank and ADA respectively. At both 5,000 and 10,000ft, the low speed branch breaks on ADA Sensor Range, where the high speed branches break on ADA Pk and stealth. This highlights the need for increased stealth at low speeds and the dominance of speed over enemy capabilities.

3. Tactical Layout Analysis

Three alternate tactical layouts provide variation in meeting time and place with various enemy forces as well as probable variation in numbers of such meetings. Each variation in this group builds on the previous one. The first variation, Tac 1, places two ADA along the coast for early warning and interdiction. The other ADA is kept closer to the objective area as a close-in defense. The second variation adds a mobile Avenger-like ADA to the tank unit. The third variation splits the mountain forces in the east to cover both sides of the pass leading to the objective area. All three variations are modeled at 1,000ft altitude.

Each tactical variation has lower Survival rates than the 1,000ft accelerated value case. In Tac 1, the overall mean Survival rate is 82%. Tac 2 and Tac 3 each have Survival rates of 72%. Additionally, Tac 2 and 3 each have a much wider variability. These differences are driven by the position of the ADA and, in the case of Tac 2 and 3, the Avenger-like mobile ADA. The important thing to look at, though, is not that the survivability rates themselves change, but whether or not the importance of the factors that enhance survivability change.

Similar to the 1,000ft standard (ALV), all three tactical layout variants have 14 or 15 terms in the MLR. The R-square values are higher in each case, ranging from 90 to 92%, compared to the base accelerated case of 86%. In Tac 1, Speed still holds as the most important factor, but is followed closely by both ADA Sensor Range and Stealth. Tac 2 and 3, on the other hand, are dominated by ADA Sensor Range and ADA Pk. Stealth follows in third and finally, Speed in a distant fourth. This change in order of important factors is again driven by the single mobile ADA that is placed with the Tank unit. The advantage gained by this unit's extra large sensor range while moving makes it very deadly. Although it still must stop, delay, then shoot, the increased sensor range allows it to accomplish these steps before the UAV is out of weapons range.

The CRT supports the MLR in all three cases. Tac 1 finds speed as the most significant factor. It again breaks at 135 knts (71 grids/time step). Second level breaks are on Tank Pk for the slow branch and ADA Sensor Range for the fast branch. For Tac 2 and Tac 3 the CRT identifies ADA Sensor Range as the top factor. In both scenarios, the second level breaks are at ADA Pk and UAV sensor range for low and high sensor range branches, respectively.

This variation set has a few serious implications. In the face of an extremely high capability threat, stealth characteristics have the dominate role. To protect against such a threat, a number a choices are available. First, this may be accomplished by UAV design, giving it the necessary low radar cross section and low thermal and noise signature. In this case, the UAV would have capabilities that would not be needed in most situations. Alternatively, in the absence of such expensive design characteristics, if such a threat is known to exist, either a jamming aircraft should be sent to accompany the

UAV, a different platform could be chosen for the mission, or the threat should be avoided. Another option would be to have an on board jamming or radar warning gear so that the UAV could automatically react to avoid the threat. Keep in mind that the enemy capabilities, in regard to both sensor range and Pk, have been tripled above an already widened capability set.

4. Threat Level Analysis

Threat Level variations explore the decision space over various enemy volumes and densities. The first two of these variations are volume variations, where two and three times the number of enemy is placed within a proportionately bigger starting box. The third variation is a pure density variation, where three times the number of enemy agents occupies the original size staring boxes. These variations are referred to as 2X Spread, 3X Spread, and 3X Density, respectively.

As expected, the overall mean Survival rate goes down in each case; 2X Spread at 75%, 3X Spread at 67%, and 3X Density at 63%. R-square ranges from 80% to 90% as the number of terms range from 11 to 15 across the three variations. UAV Speed, ADA Sensor Range, ADA Pk, and UAV Stealth are the top four factors in each variation, although they appear in different orders and magnitudes.

MLR ranks Speed as the most significant factor in the 2X Spread case, followed closely by ADA Sensor Range. ADA Pk ranks third and UAV Stealth fourth. In the 3X Spread case, the order is the same; however, Speed dominates by a much greater margin. The 3X Density case places the top three much closer in significance and ADA Sensor Range edges out Speed.

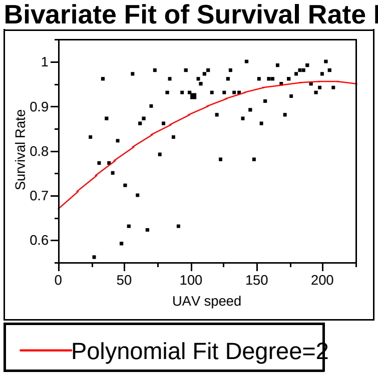
In this case, the Regression tree gives a clearer indication of how the factors break out. In each of the three variations, Speed at 135 knts is the top break point. In both 3X Spread and Density, ADA Sensor Range is next on the low speed branch and the high speed branch goes to ADA Pk then to ADA Sensor Range on both Pk branches. This shows the clear importance of Speed over any other factor. It also suggests target range values that UAV stealth characteristics, i.e., radar cross section, heat signature, noise signature, etc., would need to reduce enemy sensor ranges to for the best increases in survivability.

B. OVERALL ANALYSIS

Up to this point, the majority of the analysis has focused on speed and stealth. This does not mean that other terms are not significant, but that the magnitude of these factors continually dominates most other factors. This section will discuss some of these notable other factors, along with a recap of major factors.

Speed is the constant thread that weaves through the analysis of each scenario. A consistent value of 135 knts suggests that this should be a minimum requirement. Looking exclusively at speed's effect on survivability reveals that the speed squared term is just below the set level of significance of 0.05 in the Accelerated Base case. A simple fit of speed and speed squared versus survivability is shown in Figure 17. These two terms alone explain 37% of the variability of the data. Increases in survivability with increased speed tails off rapidly between 200 and 225 knts.

Bivariate Fit of Survival Rate By UAV speed



Polynomial Fit Degree=2

Survival Rate = 0.7683093 + 0.0011881 UAV speed - 0.0000071 (UAV speed-117.062)^2

Summary of Fit

RSquare	0.377209
RSquare Adj	0.357119
Root Mean Square Error	0.087756
Mean of Response	0.886615
Observations (or Sum Wgts)	65

Figure 17. Fit of Survival By UAV Speed and Speed Squared.

Eight of the ten scenarios indicate a UAV Speed and stealth interaction, either in the form of ADA Sensor Range or UAV Stealth. The coefficient for this term always has a negative sign, indicating diminishing returns in the presence of high values of both characteristics. In a practical sense, this means that the UAV does not need both high speed and high survivability. As has been seen, 100% stealth is sufficient at any speed.

Barring perfect stealth however, survivability is better enhanced by combining higher speeds with a moderate level of stealth. Figure 18 shows a typical interaction from the Alternate Tactical 1 layout.

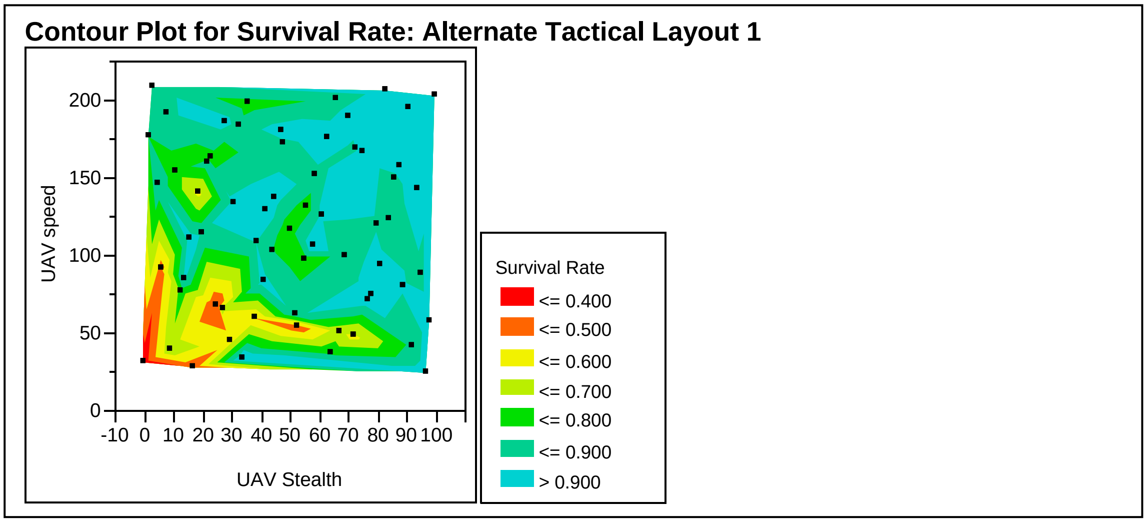


Figure 18. Contour Plot of UAV Speed and Stealth Interaction. (Best viewed in color.)

Another interaction that is significant in each scenario is between UAV Speed and various enemy capabilities. The positive value of this type of interaction indicates that higher speeds mitigate the effects of high enemy capabilities. UAV Stealth interactions with enemy capabilities are less common and take on both positive and negative values in different scenarios. Viewing ADA Sensor Range as a measure of UAV stealth, its interaction with ADA Pk is negative indicating that this type of stealth also mitigates enemy capability. Viewing ADA Sensor Range as an enemy capability indicates a deadly synergy of enemy characteristics.

Within each grouping, there are also some important findings to note. Across the altitude scenarios, as altitude increase, survivability increases. Perhaps more importantly, the variability is also reduced, despite the wide variety and range of other varied factors. The variations in tactical layout highlighted the impact that one highly capable ADA has on UAV survivability. The presence of such an asset must be dealt with either in design or at deployment using tactical avoidance or on board or external jamming. Threat level variations saw a consistent emphasis on speed regardless of enemy numbers or density.

C. NOTE ON ENDURANCE

Endurance is notably absent from the design of experiment. Endurance does have an affect on survivability; however, it can be approached in a purely computational manner. Increased endurance without increased exposure to enemy threat does not affect survivability. The discussion will then proceed assuming increased endurance is inherently implying increased exposure. For convenience, the increased exposure is assumed to be uniform in nature. In terms of a per mission basis then, as endurance goes up, survivability goes down. That is, a 2 hour mission that has a 0.90 survivability rate would have a $0.9 \times 0.9 = 0.81$ survivability rate for a 4 hour mission.

It is also important to discuss the alternatives to having a single UAV with the ability to complete the mission versus a need for multiple UAVs. These may be required due to either a communication or control relay requirement or a need for multiple UAVs to cover the entire area of interest. In the case of the former, common sense dictates the relay bird be positioned in a low threat area at higher altitude in order to maximize its survivability. Whether or not this is possible, the survivability of the system of UAVs must be considered. The survivability of the system is the product of the two individual survivability rates. Therefore, any survivability of the relay UAV that is less than unity will reduce the system's survivability. In the latter case, not only is the system survivability the product of the individual survivability rates (which is the same for each UAV here), but additional transit routes required for each UAV to cover its assigned area also increases exposure. This exposure can again be minimized by transiting in low threat areas and/or at higher altitudes and speeds.

D. CONCLUSIONS AND RECOMMENDATIONS

Warfighters are increasingly relying on UAV systems at all levels of combat operations. As theses systems weave further into the fabric of our tactics and doctrine, their loss will seriously diminish combat effectiveness. This makes the survivability of these systems of utmost importance. Using Agent-based modeling and NOLH design of experiment, numerous factors and levels are explored to gain insight into their impact on, and relative importance to, survivability.

Initial exploration is based on the most realistic values of friendly and enemy capabilities. Even so, each factor is varied over a wide enough range to go beyond expected capability levels. This base case scenario yields appropriate survivability rates, validating the modeling effort. Results in this case indicate that UAV Speed and Stealth are of equal importance. An interaction between UAV Speed and ADA sensor range shows initial potential that speed can mitigate enemy capabilities. This model allows for very limited sensitivity, however, due to the high survival rates.

To increase sensitivity to model inputs, a simulation version of Accelerated Life Testing is applied. By increasing both enemy sensor ranges and Pk values, a more lethal environment is created, allowing enhanced distinction between good and better improvements. Using this technique, speed is consistently found to be the dominating factor across nearly all scenarios. Within the scope of this model, the analysis suggests that a speed of at least 135 knts should be required and that increases in survivability remain appreciable up to 200 to 225 knts. The exception to speed's dominance is in the face of extremely high enemy capability assets. In this case, stealth becomes more important than speed alone. Total stealth always produces 100% survivability. However, the interactions indicate that as both speed and stealth increase, speed yields a faster return on overall survivability and that speed mitigates increased enemy capabilities.

Stealth is considered in two parts due to modeling constraints; a camouflage aspect based on glimpse probability, and as a reduction of enemy senor range. The latter type is, in general, the second most important characteristic. Its importance increases as enemy capabilities increase and as altitude increases. Finally, concerning altitude, increased altitude produces higher mean survivability as well as decreased variability. Each of these aspects must be taken into consideration in determining the requirements of VUAV. In conjunction with the work of Raffetto (2004), various combinations of characteristics can be evaluated in terms of both survivability and efficiency. Though not predictive in nature, the Multiple Linear Regression model can be used when comparing different characteristic sets, providing a useful compliment to Raffetto's performance efficiency model.

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APPENDIX A: INPUT DESIGNS AND OUPUT DATA

The following tables contain the input values used in each excursion of each scenario. The base case shows all values of all variables. The first page contains the values included in the NOLH design of experiment. The second page contains values that are varied in step with the NOLH values. The third page contains values that duplicate previous values, i.e., Infantry Pk values are the same for each Infantry squad The next table shows only the values generated by the NOLH and those values varied synchronously with that design. Duplicate values are not shown in this case.

The balance of the scenario tables shows only values that differ from the 1,000ft accelerated case. Altitude scenarios differ only in Tank and ADA Sensor ranges. Alternate Tactical Layout 1 (Tac 1) uses the same values as 1,000ft accelerated case. The mobile ADA in Tac 2 and Tac 3 uses sensor range values from ADA sensor range, state 4, in all four states. Threat Level scenarios also uses the same values as the 1,000ft accelerated case with additional ADA mirroring the values of like agents.

The MANA scenario files and the Tiller generated batch files used in the execution of all runs are available from the author or advisor.

1. BASE CASE (NON-ACCEL)

Low Level	0	0	10	3	25	5	0	1	0	10	0	0.85
High Level	100	100	100	50	183	100	10	10	6	500	27	1
Factor code	A	B	C	D	E	F	G	H	I	J	K	Survival
Excursion #												Rate
0	71	4	42	8	146	80	4	9	4	277	25	1
1	95	71	19	19	64	56	7	7	5	385	13	0.99
2	89	35	95	16	160	19	4	4	3	400	23	0.98
3	64	89	74	5	91	30	2	2	5	454	16	0.98
4	92	46	26	7	50	28	6	6	2	40	22	1
5	53	92	31	10	128	18	8	9	0	209	21	0.99
6	76	18	57	14	77	89	4	2	2	178	24	0.99
7	81	76	92	20	170	71	0	3	1	17	17	1
8	68	3	11	22	121	42	0	8	1	423	10	1
9	96	68	53	3	69	92	3	7	0	339	0	1
10	51	1	97	12	94	34	6	1	1	362	5	1
11	98	51	71	11	35	40	8	3	2	270	6	0.99
12	54	21	39	21	101	22	2	9	5	78	1	1
13	78	54	47	15	178	9	0	5	3	132	8	1
14	57	32	80	23	59	49	9	2	4	10	11	0.97
15	67	57	59	9	175	100	5	5	4	186	2	0.99
16	85	43	45	34	183	79	9	6	3	163	7	1
17	56	85	33	30	96	83	7	4	4	63	0	0.98
18	73	39	60	39	165	7	4	5	4	247	2	0.99
19	60	73	87	28	52	46	1	8	5	32	11	0.99
20	82	20	46	49	84	6	7	3	0	216	4	1
21	79	82	10	27	136	51	8	2	2	461	8	0.99
22	100	40	81	48	45	73	1	6	1	285	7	1
23	59	100	84	35	109	59	2	10	0	354	5	0.96
24	62	25	18	41	141	94	1	1	0	140	17	0.99
25	75	62	24	38	55	65	3	4	2	25	23	0.99
26	84	9	77	27	168	36	9	7	1	117	16	1
27	90	84	66	46	74	16	6	7	2	193	26	0.98
28	93	29	21	33	57	43	0	2	5	438	14	0.99
29	70	93	40	44	180	37	5	1	4	308	18	1
30	65	12	73	47	89	77	7	9	5	408	14	1
31	87	65	94	36	126	91	6	6	3	415	20	0.98
32	50	50	55	26	104	52	5	5	3	255	13	0.99
33	28	95	67	44	62	24	5	1	1	232	1	0.98
34	4	28	90	33	143	48	2	3	0	124	13	0.97
35	10	64	14	36	47	85	5	6	2	109	3	0.99
36	35	10	35	47	116	74	7	8	0	55	10	0.97
37	7	53	83	45	158	76	3	4	3	469	4	0.96
38	46	7	78	42	79	86	1	1	5	300	5	0.98
39	23	81	52	38	131	15	5	8	3	331	2	1
40	18	23	17	32	37	33	9	7	4	492	9	0.94
41	31	96	98	30	87	62	9	2	4	86	16	0.99
42	3	31	56	50	138	12	6	3	6	170	26	0.96
43	48	98	12	40	114	70	3	9	4	147	21	0.97
44	1	48	38	41	173	64	1	7	3	239	20	0.99
45	45	78	70	31	106	82	7	1	0	431	25	0.95
46	21	45	62	37	30	95	10	5	2	377	18	0.88
47	42	67	29	29	148	55	0	8	1	500	15	1
48	32	42	50	43	32	5	4	5	1	323	24	0.85
49	14	56	64	18	25	25	0	4	2	346	19	0.85
50	43	14	76	22	111	21	2	6	1	446	27	1
51	26	60	49	13	42	97	5	5	1	262	24	0.93
52	39	26	22	24	155	58	8	2	0	477	15	0.99
53	17	79	63	3	123	98	2	7	5	293	22	0.97
54	20	17	100	25	72	53	1	8	3	48	18	0.96
55	0	59	28	4	163	31	8	4	4	224	19	0.98
56	40	0	25	17	99	45	7	1	5	155	21	0.98
57	37	75	91	11	67	10	8	9	5	369	9	0.95
58	25	37	85	14	153	39	6	6	3	484	3	0.99
59	15	90	32	25	40	68	0	3	4	392	10	0.98
60	9	15	43	6	133	88	3	3	3	316	0	0.95
61	6	70	88	19	151	61	9	8	0	71	12	0.97
62	29	6	69	8	27	67	4	9	1	201	8	0.97
63	34	87	36	5	119	27	2	1	0	101	12	1
64	12	34	15	16	82	13	3	4	2	94	6	0.99

Factors varied per NOLH design

A	UAV Stealth
B	UAV Enemy
C	UAV Nxt wy pt
D	UAV Sns rng
E	UAV Speed
F	Tank Pk pt1 st1
G	Tank Sns rng st1
H	Inf 3 Pk pt1 st1
I	Inf 3 sns rng st1
J	ADA 1 Pk st4
K	ADA 1 sns rng st4

Low Level	1	1	1
High Level	30	10	5
Factor code	L	M	N
Excursion #			
0	24	8	5
1	17	6	4
2	5	2	2
3	9	3	1
4	8	3	3
5	5	2	5
6	27	9	1
7	21	7	2
8	12	5	4
9	28	9	4
10	10	4	1
11	12	4	2
12	6	3	5
13	2	1	3
14	14	5	1
15	30	10	3
16	24	8	3
17	25	8	2
18	2	1	3
19	14	5	4
20	1	1	2
21	15	5	1
22	22	7	3
23	17	6	5
24	28	9	1
25	19	7	2
26	10	4	4
27	4	2	4
28	13	5	1
29	11	4	1
30	23	8	5
31	27	9	3
32	15	5	3
33	7	3	1
34	14	5	2
35	25	9	3
36	22	8	4
37	23	8	2
38	26	9	1
39	4	2	4
40	10	4	4
41	18	6	1
42	3	2	2
43	21	7	5
44	19	7	4
45	25	8	1
46	28	10	3
47	16	6	4
48	1	1	3
49	7	3	2
50	6	3	3
51	29	10	3
52	17	6	1
53	29	10	4
54	16	6	4
55	9	3	2
56	13	5	1
57	3	1	5
58	11	4	3
59	20	7	2
60	26	9	2
61	18	6	4
62	20	7	5
63	8	3	1
64	3	2	2

Synchronously varied factors	L	Tank Pk pt2 st1
	M	Tank Pk pt3 st1
	N	Inf_3_ Pk pt2 st1

Low Level	0	5	1	1	0	1	1	0	0	0
High Level	18	100	30	10	10	10	5	6	18	18
Factor code	P	Q	R	S	T	U	V	W	X	Y
Excursion #										
0	17	80	24	8	4	9	5	4	17	17
1	9	56	17	6	7	7	4	5	9	9
2	15	19	5	2	4	4	2	3	15	15
3	11	30	9	3	2	2	1	5	11	11
4	15	28	8	3	6	6	3	2	15	15
5	14	18	5	2	8	9	5	0	14	14
6	16	89	27	9	4	2	1	2	16	16
7	11	71	21	7	0	3	2	1	11	11
8	7	42	12	5	0	8	4	1	7	7
9	0	92	28	9	3	7	4	0	0	0
10	3	34	10	4	6	1	1	1	3	3
11	4	40	12	4	8	3	2	2	4	4
12	1	22	6	3	2	9	5	5	1	1
13	5	9	2	1	0	5	3	3	5	5
14	7	49	14	5	9	2	1	4	7	7
15	1	100	30	10	5	5	3	4	1	1
16	5	79	24	8	9	6	3	3	5	5
17	0	83	25	8	7	4	2	4	0	0
18	1	7	2	1	4	5	3	4	1	1
19	7	46	14	5	1	8	4	5	7	7
20	3	6	1	1	7	3	2	0	3	3
21	5	51	15	5	8	2	1	2	5	5
22	5	73	22	7	1	6	3	1	5	5
23	3	59	17	6	2	10	5	0	3	3
24	11	94	28	9	1	1	1	0	11	11
25	15	65	19	7	3	4	2	2	15	15
26	11	36	10	4	9	7	4	1	11	11
27	17	16	4	2	6	7	4	2	17	17
28	9	43	13	5	0	2	1	5	9	9
29	12	37	11	4	5	1	1	4	12	12
30	9	77	23	8	7	9	5	5	9	9
31	13	91	27	9	6	6	3	3	13	13
32	9	52	15	5	5	5	3	3	9	9
33	1	24	7	3	5	1	1	1	1	1
34	9	48	14	5	2	3	2	0	9	9
35	2	85	25	9	5	6	3	2	2	2
36	7	74	22	8	7	8	4	0	7	7
37	3	76	23	8	3	4	2	3	3	3
38	3	86	26	9	1	1	1	5	3	3
39	1	15	4	2	5	8	4	3	1	1
40	6	33	10	4	9	7	4	4	6	6
41	11	62	18	6	9	2	1	4	11	11
42	17	12	3	2	6	3	2	6	17	17
43	14	70	21	7	3	9	5	4	14	14
44	13	64	19	7	1	7	4	3	13	13
45	17	82	25	8	7	1	1	0	17	17
46	12	95	28	10	10	5	3	2	12	12
47	10	55	16	6	0	8	4	1	10	10
48	16	5	1	1	4	5	3	1	16	16
49	13	25	7	3	0	4	2	2	13	13
50	18	21	6	3	2	6	3	1	18	18
51	16	97	29	10	5	5	3	1	16	16
52	10	58	17	6	8	2	1	0	10	10
53	15	98	29	10	2	7	4	5	15	15
54	12	53	16	6	1	8	4	3	12	12
55	13	31	9	3	8	4	2	4	13	13
56	14	45	13	5	7	1	1	5	14	14
57	6	10	3	1	8	9	5	5	6	6
58	2	39	11	4	6	6	3	3	2	2
59	7	68	20	7	0	3	2	4	7	7
60	0	88	26	9	3	3	2	3	0	0
61	8	61	18	6	9	8	4	0	8	8
62	5	67	20	7	4	9	5	1	5	5
63	8	27	8	3	2	1	1	0	8	8
64	4	13	3	2	3	4	2	2	4	4

Factors with duplicated values	P	ADA1 sns rng st1	U	Inf_3_ pt1 st2
	Q	Tank Pk pt1 st2	V	Inf_3_ Pk pt2 st2
	R	Tank Pk pt 2 st 2	W	Inf 3 sns rng st2l
	S	Tank Pk pt3 st2	X	ADA1 sns rng st2
	T	Tank sns rng st2	Y	ADA1 sns rng st3

2. Accelerated base, 1,000 ft

factor code	A	B	C	D	E	F	G	H	I	J	K	Survival Rate
low level	0	0	10	3	25	5	0	1	0	0	10	
high level	100	100	100	50	209	300	30	30	18	81	1500	
Excursion #												
0	72	5	42	18	48	231	24	22	10	78	732	0.59
1	95	72	20	23	88	79	16	28	14	58	1128	0.83
2	89	36	96	13	80	259	5	18	14	33	685	0.86
3	64	89	75	24	37	129	8	30	16	10	406	0.87
4	92	47	27	4	42	51	8	15	1	49	918	0.75
5	53	92	31	26	54	199	4	4	7	72	1290	0.63
6	77	19	58	4	71	102	27	14	6	13	639	0.9
7	81	77	93	18	94	277	21	10	0	20	33	0.93
8	69	3	11	41	100	185	12	10	15	65	150	0.93
9	97	69	54	39	25	88	28	1	12	54	569	0.83
10	52	2	97	28	62	134	9	8	13	1	1034	0.86
11	98	52	72	46	57	23	11	12	10	25	1221	0.97
12	55	22	40	33	97	148	6	29	3	77	429	0.98
13	78	55	48	45	74	291	1	16	5	42	10	0.98
14	58	33	80	48	106	70	14	25	0	11	1407	0.96
15	67	58	59	37	51	286	30	25	6	37	848	0.72
16	86	44	45	9	149	300	23	18	6	47	1453	0.78
17	56	86	34	19	131	139	25	22	2	29	1197	0.98
18	73	39	61	17	169	268	1	24	9	43	615	0.95
19	61	73	87	6	126	56	13	26	1	66	266	0.93
20	83	20	47	7	206	116	0	4	8	24	1058	0.98
21	80	83	10	10	120	212	15	11	17	14	1337	0.88
22	100	41	82	15	203	42	22	11	10	46	196	1
23	59	100	85	21	152	162	17	3	13	81	336	0.96
24	63	25	18	31	175	222	28	6	5	8	243	0.96
25	75	63	24	50	166	60	19	14	1	30	545	0.99
26	84	9	78	40	123	272	10	8	4	62	1430	0.78
27	91	84	66	42	195	97	4	11	7	59	988	0.93
28	94	30	21	32	143	65	12	26	16	18	126	1
29	70	94	41	38	189	295	10	24	11	5	802	0.99
30	66	13	73	29	200	125	23	29	15	75	1151	0.97
31	88	66	94	43	157	194	27	19	15	53	1011	0.91
32	50	50	55	27	117	153	15	16	9	41	755	0.93
33	28	95	68	35	186	74	6	9	8	3	778	0.98
34	5	28	90	30	146	226	14	3	4	23	383	0.89
35	11	64	14	40	154	46	25	13	4	48	825	0.86
36	36	11	35	29	198	176	22	1	2	71	1104	0.94
37	8	53	83	49	192	254	23	16	17	32	592	0.95
38	47	8	79	27	180	106	26	27	11	9	220	0.97
39	23	81	52	49	163	203	3	17	12	68	871	0.96
40	19	23	17	35	140	28	9	21	18	61	1477	0.87
41	31	97	99	12	134	120	18	21	3	16	1360	0.93
42	3	31	56	14	209	217	2	30	6	27	941	0.94
43	48	98	13	25	172	171	21	23	5	80	476	0.88
44	2	48	38	7	177	282	19	19	8	56	289	0.92
45	45	78	70	20	137	157	24	2	15	4	1081	0.93
46	22	45	62	8	160	14	29	15	14	39	1500	0.96
47	42	67	30	5	129	235	16	6	18	70	103	0.96
48	33	42	51	16	183	19	0	6	12	44	662	0.98
49	14	56	65	44	85	5	7	13	12	34	57	0.96
50	44	14	76	34	103	166	5	9	16	52	313	0.92
51	27	61	49	36	65	37	29	7	9	38	895	0.87
52	39	27	23	47	108	249	17	5	17	15	1244	0.95
53	17	80	63	46	28	189	30	27	10	57	452	0.56
54	20	17	100	43	114	93	15	20	1	67	173	0.98
55	0	59	28	38	31	263	8	20	8	35	1314	0.77
56	41	0	25	32	83	143	13	28	5	0	1174	0.93
57	38	75	92	22	60	83	2	25	13	73	1267	0.7
58	25	38	86	3	68	245	11	17	17	51	965	0.62
59	16	91	33	13	111	33	20	23	14	19	80	0.97
60	9	16	44	11	39	208	26	20	11	22	522	0.77
61	6	70	89	21	91	240	18	5	2	63	1384	0.63
62	30	6	69	15	45	10	20	7	7	76	708	0.82
63	34	88	37	24	34	180	7	2	3	6	359	0.96
64	13	34	16	10	77	111	3	12	3	28	499	0.79

Factors varied per NOLH design					
A	UAV Stealth	D	UAV sensor range	H	Infantry Pk pt1 st1
B	UAV enemy attracti	E	UAV Speed	I	Infantry seneor range st1
C	UAV next waypt	F	Tank Pk pt1 st1	J	ADA senesor range st4
		G	Tank sensor range	K	ADA Pk st4

low level	1	1	5	0	1	1	0	0
high level	90	30	300	30	15	30	18	54
factor code	L	M	N	R	S	T	V	W
Excursion #								
0	69	23	231	24	11	22	10	52
1	23	8	79	16	14	28	14	39
2	77	26	259	5	9	18	14	22
3	39	13	129	8	15	30	16	7
4	15	6	51	8	8	15	1	33
5	59	20	199	4	3	4	7	48
6	30	11	102	27	7	14	6	8
7	83	28	277	21	5	10	0	14
8	55	19	185	12	5	10	15	43
9	26	9	88	28	1	1	12	36
10	40	14	134	9	4	8	13	1
11	7	3	23	11	6	12	10	17
12	44	15	148	6	14	29	3	51
13	87	29	291	1	8	16	5	28
14	20	7	70	14	13	25	0	8
15	86	29	286	30	12	25	6	24
16	90	30	300	23	9	18	6	31
17	41	14	139	25	11	22	2	19
18	80	27	268	1	12	24	9	29
19	16	6	56	13	13	26	1	44
20	34	12	116	0	2	4	8	16
21	64	21	212	15	6	11	17	9
22	12	5	42	22	6	11	10	30
23	48	16	162	17	2	3	13	54
24	66	22	222	28	3	6	5	5
25	18	6	60	19	7	14	1	20
26	82	27	272	10	5	8	4	41
27	29	10	97	4	6	11	7	40
28	19	7	65	12	13	26	16	12
29	89	30	295	10	12	24	11	3
30	37	13	125	23	15	29	15	50
31	58	20	194	27	10	19	15	35
32	46	16	153	15	8	16	9	27
33	22	8	74	6	5	9	8	2
34	68	23	226	14	2	3	4	15
35	14	5	46	25	7	13	4	32
36	52	18	176	22	1	1	2	47
37	76	25	254	23	8	16	17	21
38	32	11	106	26	13	27	11	6
39	61	20	203	3	9	17	12	46
40	8	3	28	9	11	21	18	41
41	36	12	120	18	11	21	3	11
42	65	22	217	2	15	30	6	18
43	51	17	171	21	12	23	5	53
44	84	28	282	19	10	19	8	37
45	47	16	157	24	2	2	15	3
46	4	2	14	29	8	15	14	26
47	71	24	235	16	3	6	18	46
48	5	2	19	0	4	6	12	30
49	1	1	5	7	7	13	12	23
50	50	17	166	5	5	9	16	35
51	11	4	37	29	4	7	9	25
52	75	25	249	17	3	5	17	10
53	57	19	189	30	14	27	10	38
54	27	10	93	15	10	20	1	45
55	79	26	263	8	10	20	8	24
56	43	15	143	13	14	28	5	0
57	25	9	83	2	13	25	13	49
58	73	25	245	11	9	17	17	34
59	9	4	33	20	12	23	14	13
60	62	21	208	26	10	20	11	14
61	72	24	240	18	3	5	2	42
62	2	1	10	20	4	7	7	51
63	54	18	180	7	1	2	3	4
64	33	11	111	3	6	12	3	19

Factor values varied in direct correlation with those in NOLH design

L	Tank Pk pt2 st1	P	Tank sns rng st2	S	Inf 3 sns rng st2
M	Tank Pk pt3 st1	Q	Inf_3_ Pk pt2 st1	T	ADA1 sns rng st1
N	Tank Pk pt1 st2	R	Inf_3_ Pk pt1 st2		

3. 5,000FT DIFFERENCES

Excursion #	Tank sns rng st1	ADA_1_ sns rng st4	ADA1 sns rng st1	Blue survive
0	24	78	52	0.73
1	16	58	39	0.94
2	5	33	22	0.88
3	8	10	7	0.93
4	8	49	33	0.8
5	4	72	48	0.7
6	27	13	8	0.98
7	21	20	14	0.94
8	12	65	43	0.87
9	28	54	36	0.9
10	9	1	1	0.88
11	11	25	17	0.96
12	6	77	51	0.92
13	1	42	28	0.97
14	14	11	8	1
15	30	37	24	0.8
16	23	47	31	0.86
17	25	29	19	0.99
18	1	43	29	0.97
19	13	66	44	0.96
20	0	24	16	0.99
21	15	14	9	0.91
22	22	46	30	1
23	17	81	54	0.9
24	28	8	5	0.99
25	19	30	20	0.99
26	10	62	41	0.75
27	4	59	40	0.97
28	12	18	12	1
29	10	5	3	0.99
30	23	75	50	0.94
31	27	53	35	0.95
32	15	41	27	0.97
33	6	3	2	0.98
34	14	23	15	0.96
35	25	48	32	0.94
36	22	71	47	0.97
37	23	32	21	0.98
38	26	9	6	0.99
39	3	68	46	0.97
40	9	61	41	0.87
41	18	16	11	0.96
42	2	27	18	0.99
43	21	80	53	0.97
44	19	56	37	0.94
45	24	4	3	0.96
46	29	39	26	0.98
47	16	70	46	0.98
48	0	44	30	1
49	7	34	23	1
50	5	52	35	0.94
51	29	38	25	0.91
52	17	15	10	0.95
53	30	57	38	0.78
54	15	67	45	0.98
55	8	35	24	0.92
56	13	0	0	1
57	2	73	49	0.76
58	11	51	34	0.65
59	20	19	13	0.99
60	26	22	14	0.83
61	18	63	42	0.71
62	20	76	51	0.8
63	7	6	4	0.99
64	3	28	19	0.86

4. 10,000FT DIFFERENCES

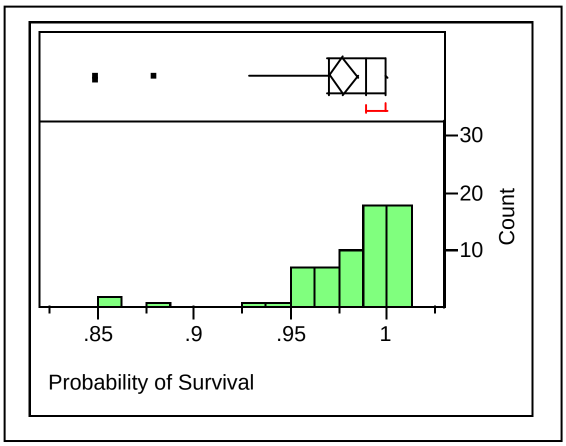
Excursion_Number	ADA_1_ sns rng st4	ADA1 sns rng st1	Blue survive
0	78	52	0.82
1	58	39	0.95
2	33	22	0.93
3	10	7	0.99
4	49	33	0.78
5	72	48	0.79
6	13	8	0.97
7	20	14	1
8	65	43	0.91
9	54	36	0.88
10	1	1	1
11	25	17	1
12	77	51	0.97
13	42	28	1
14	11	8	1
15	37	24	0.87
16	47	31	0.92
17	29	19	1
18	43	29	0.99
19	66	44	0.98
20	24	16	0.94
21	14	9	0.93
22	46	30	1
23	81	54	0.98
24	8	5	1
25	30	20	0.98
26	62	41	0.79
27	59	40	0.93
28	18	12	1
29	5	3	1
30	75	50	0.95
31	53	35	0.92
32	41	27	0.99
33	3	2	1
34	23	15	1
35	48	32	0.98
36	71	47	0.99
37	32	21	1
38	9	6	1
39	68	46	0.99
40	61	41	0.93
41	16	11	1
42	27	18	0.99
43	80	53	0.98
44	56	37	1
45	4	3	1
46	39	26	1
47	70	46	0.99
48	44	30	0.99
49	34	23	1
50	52	35	0.98
51	38	25	0.91
52	15	10	1
53	57	38	0.84
54	67	45	0.99
55	35	24	0.98
56	0	0	1
57	73	49	0.85
58	51	34	0.93
59	19	13	1
60	22	14	0.92
61	63	42	0.94
62	76	51	0.88
63	6	4	1
64	28	19	0.97

APPENDIX B: LINEAR REGRESSION, CLASSIFICATION TREES, AND LOGISTIC REGRESSION TABLES AND PLOTS

This appendix contains the entire raw analytical effort on the data generated by the simulation runs. Each scenario section contains Linear Regression output, Classification and Regression Trees, and various plots. Logistic regression is also included for comparison. Additionally, some analysis across each scenario group is provided.

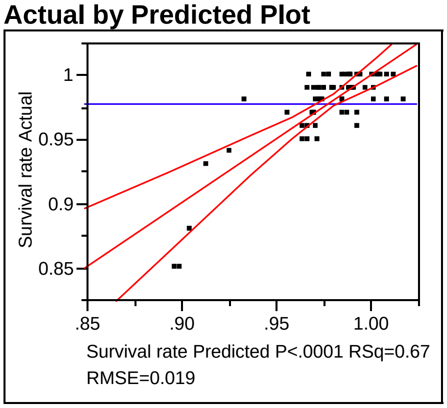
1. BASE CASE

Distributions
Survival Rate Distribution of Mean Survival Rate Over Each Design Point



Moments	
Mean	0.9776923
Std Dev	0.0310126
Std Err Mean	0.0038466
upper 95% Mean	0.9853768
lower 95% Mean	0.9700078
N	65

Response Survival rate
Whole Model Base Run
Actual by Predicted Plot



Summary of Fit

RSquare	0.66612
RSquare Adj	0.625117
Root Mean Square Error	0.018988
Mean of Response	0.977692
Observations (or Sum Wgts)	65

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	7	0.04100223	0.005857	16.2457
Error	57	0.02055162	0.000361	Prob > F
C. Total	64	0.06155385		<.0001

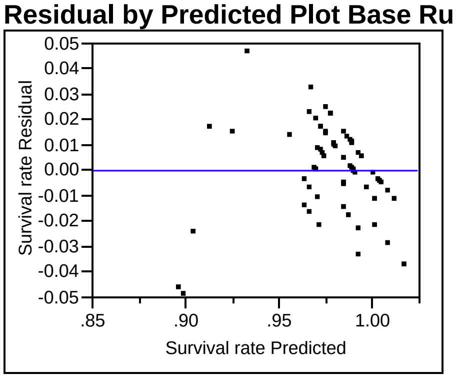
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.9555887	0.009456	101.05	<.0001
UAV Stealth	0.0004527	0.00008	5.63	<.0001
UAV speed	0.0002748	0.000051	5.39	<.0001
ADA2 sns rng st4	-0.000923	0.000297	-3.10	0.0030
ADA2 Pk st4	-0.000038	0.000016	-2.30	0.0250
(UAV speed-103.769)*(ADA2 sns rng st4-13.0154)	0.0000299	0.000007	4.24	<.0001
(UAV speed-103.769)*(ADA2 Pk st4-254.523)	9.2446e-7	3.862e-7	2.39	0.0200
(UAV speed-103.769)*(UAV speed-103.769)	-0.000003	0.000001	-2.62	0.0112

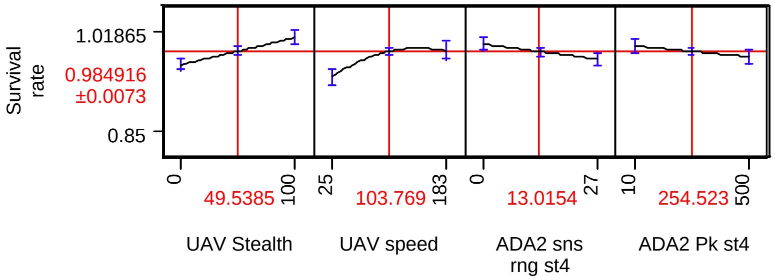
Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
UAV Stealth	1	1	0.01144364	31.7390	<.0001
UAV speed	1	1	0.01048207	29.0721	<.0001
ADA2 sns rng st4	1	1	0.00347260	9.6313	0.0030
ADA2 Pk st4	1	1	0.00190968	5.2965	0.0250
UAV speed*ADA2 sns rng st4	1	1	0.00647320	17.9535	<.0001
UAV speed*ADA2 Pk st4	1	1	0.00206565	5.7291	0.0200
UAV speed*UAV speed	1	1	0.00247650	6.8686	0.0112

Residual by Predicted Plot Base Run

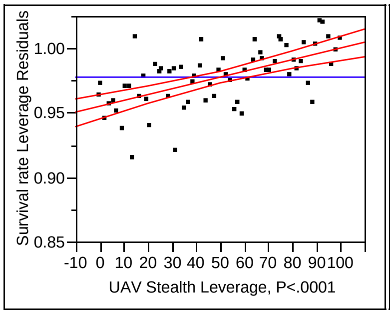


Prediction Profiler

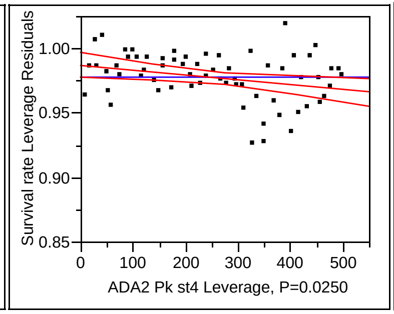


Leverage Plots

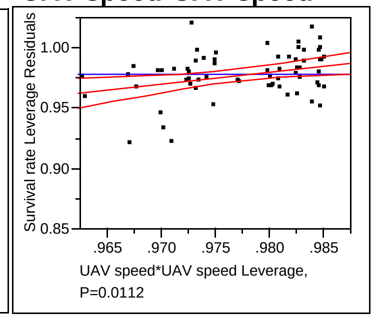
UAV Stealth



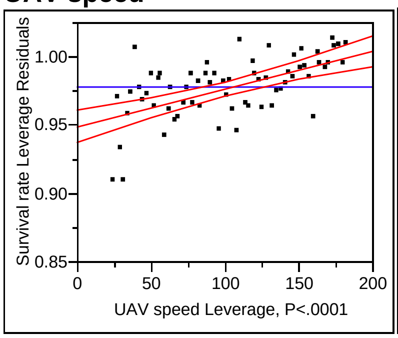
ADA2 Pk st4



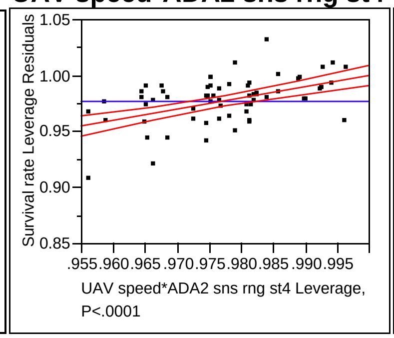
UAV speed*UAV speed



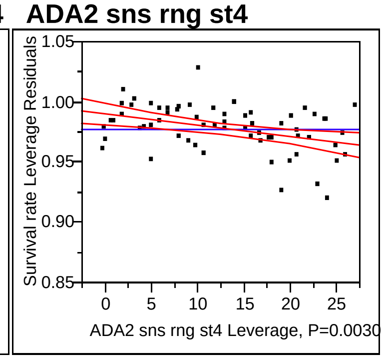
UAV speed



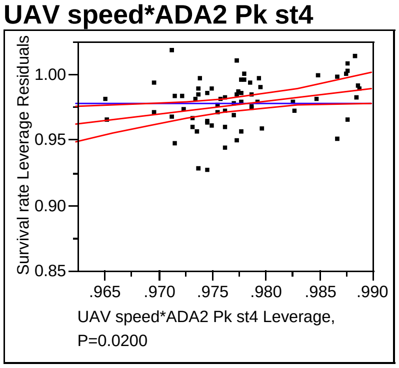
UAV speed*ADA2 sns rng st4



ADA2 sns rng st4



UAV speed*ADA2 Pk st4

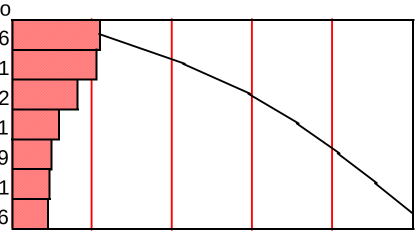


Effect Screening

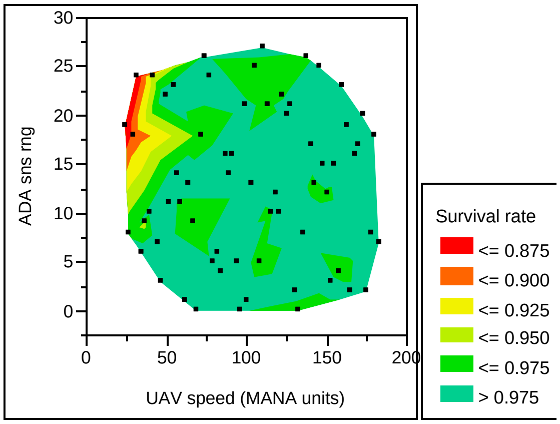
	Lenth PSE
t-Test Scale	4.814865
Coded Scale	0.01134

Pareto Plot of Estimates

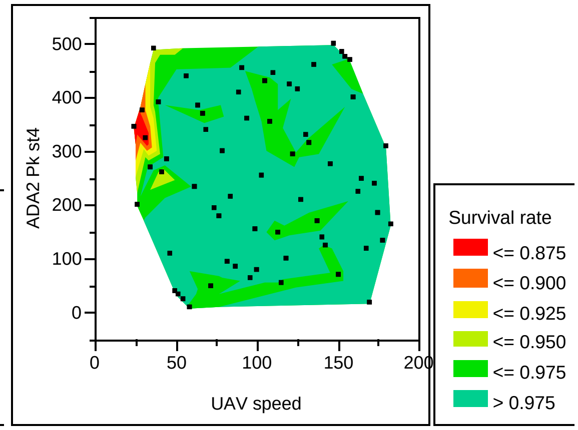
Term	t Ratio
UAV Stealth	5.633736
UAV speed	5.391851
(UAV speed-103.769)*(ADA2 sns rng st4-13.0154)	4.237152
ADA2 sns rng st4	-3.103431
(UAV speed-103.769)*(UAV speed-103.769)	-2.620799
(UAV speed-103.769)*(ADA2 Pk st4-254.523)	2.393551
ADA2 Pk st4	-2.301416



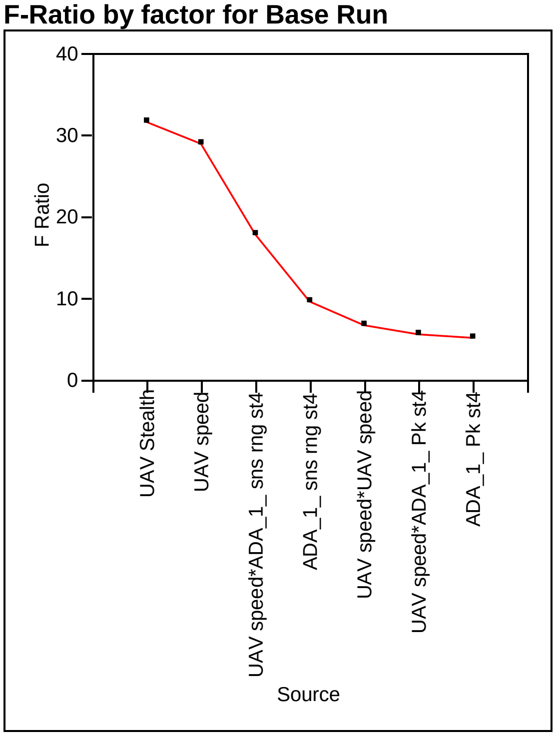
Contour Plot for Survival rate



Contour Plot for Survival rate

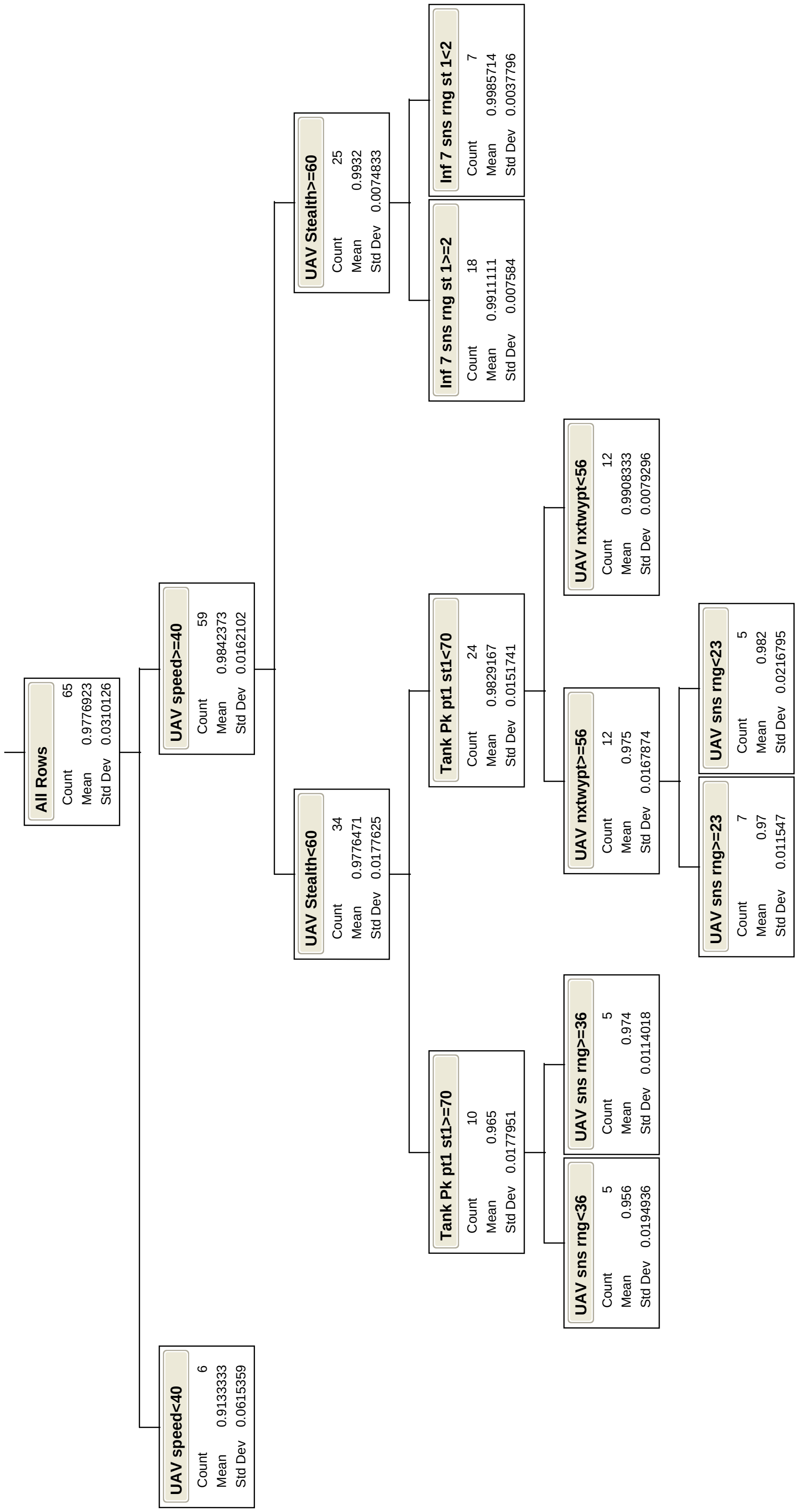


F-Ratio by factor for Base Run



Partition for Survival rate

RSquare	N	Imputes
0.587	65	0



Nominal Logistic Fit for Blue survive

Whole Model Test

-LogLikelihood	DF	ChiSquare	Prob>ChiSq
85.89705	16	171.7941	<.0001
608.88292			
694.77997			

RSquare (U)	0.1236
Observations (or Sum Wgts)	6500

Converged by Objective

Lack Of Fit

Source	DF	-LogLikelihood	ChiSquare
Lack Of Fit	48	19.69433	39.38866
Saturated	64	589.18859	Prob>ChiSq
Fitted	16	608.88292	0.8075

Parameter Estimates

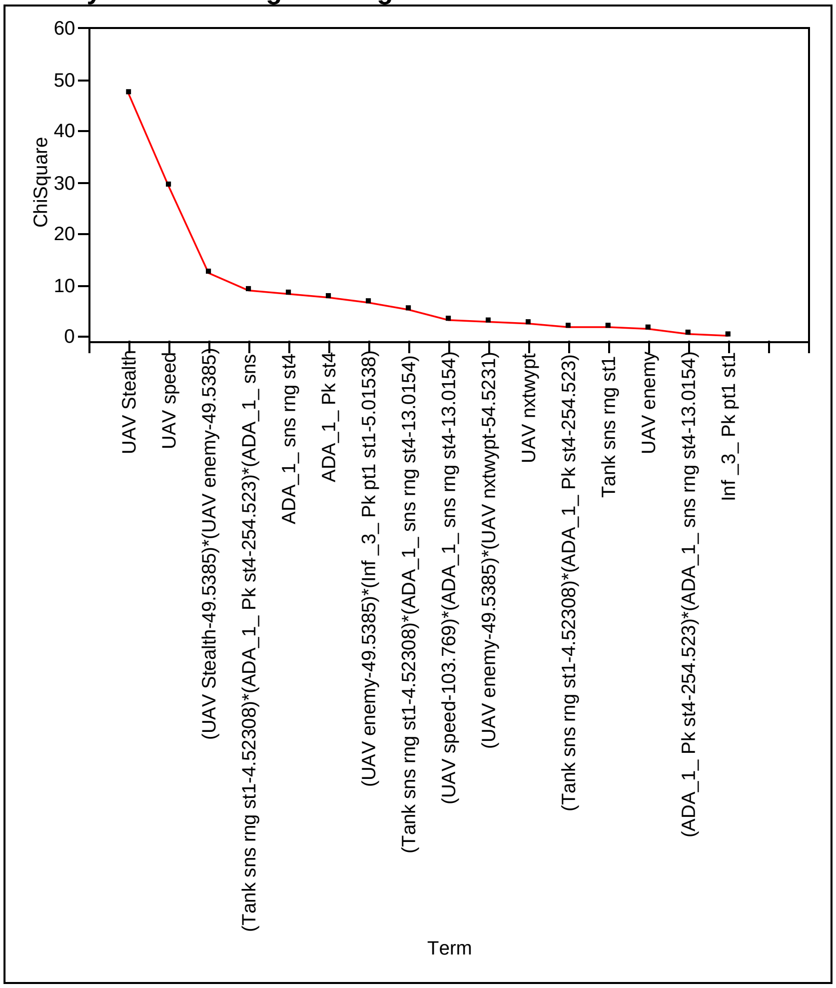
Estimate	Std Error	ChiSquare	Prob>ChiSq
-3.513223	0.5302322	43.90	<.0001
-0.0280953	0.0040923	47.13	<.0001
0.00533634	0.0042459	1.58	0.2088
0.0059399	0.0037716	2.48	0.1153
-0.0125741	0.0023196	29.38	<.0001
0.04764719	0.0340073	1.96	0.1612
-0.0205485	0.0418533	0.24	0.6235
0.00213649	0.0007661	7.78	0.0053
0.03853166	0.0134012	8.27	0.0040
0.00066238	0.000187	12.55	0.0004
0.00023185	0.0001387	2.79	0.0947
0.00298411	0.0011527	6.70	0.0096
-0.0005501	0.0003007	3.35	0.0674
-0.0003516	0.0002499	1.98	0.1594
-0.0150732	0.0066549	5.13	0.0235
0.00006942	0.0001061	0.43	0.5131
0.00015469	0.0000514	9.06	0.0026

For log odds of 0/1

Effect Wald Tests

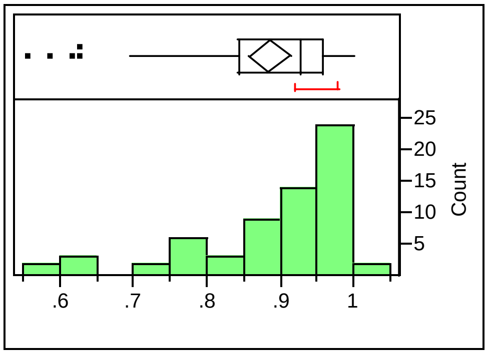
Source	Nparm	DF	Wald ChiSquare	Prob>ChiSq
UAV Stealth	1	1	47.1333682	0.0000
UAV enemy	1	1	1.57961912	0.2088
UAV nxtwypt	1	1	2.48034921	0.1153
UAV speed	1	1	29.3848743	0.0000
Tank sns rng st1	1	1	1.96304671	0.1612
Inf _3_ Pk pt1 st1	1	1	0.24104769	0.6235
ADA_1_ Pk st4	1	1	7.77632783	0.0053
ADA_1_ sns rng st4	1	1	8.26695766	0.0040
UAV Stealth*UAV enemy	1	1	12.5468221	0.0004
UAV enemy*UAV nxtwypt	1	1	2.79256501	0.0947
UAV enemy*Inf _3_ Pk pt1 st1	1	1	6.70224358	0.0096
UAV speed*ADA_1_ sns rng st4	1	1	3.3459719	0.0674
Tank sns rng st1*ADA_1_ Pk st4	1	1	1.97952917	0.1594
Tank sns rng st1*ADA_1_ sns rng st4	1	1	5.13009599	0.0235
ADA_1_ Pk st4*ADA_1_ sns rng st4	1	1	0.42783443	0.5131
Tank sns rng st1*ADA_1_ Pk st4*ADA_1_ sns rng st4	1	1	9.06086028	0.0026

Overlay Plot from Logistic Regression



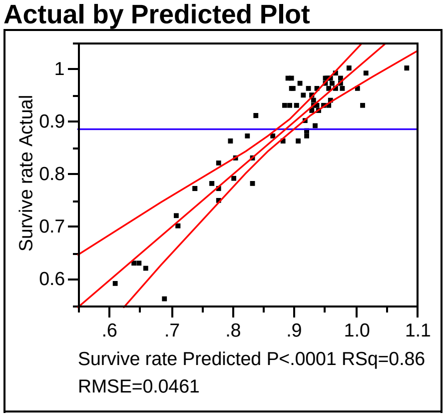
2. ACCELERATED LIFE VALUES, 1,000FT ALTITUDE

Distributions
Survival Rate



Moments	
Mean	0.8866154
Std Dev	0.1094486
Std Err Mean	0.0135754
upper 95% Mean	0.9137354
lower 95% Mean	0.8594954
N	65

Response Survive rate 1000ft Accelerated Values
Actual by Predicted Plot



Summary of Fit

RSquare	0.861132
RSquare Adj	0.822249
Root Mean Square Error	0.046144
Mean of Response	0.886615
Observations (or Sum Wgts)	65

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	14	0.66019172	0.047157	22.1468
Error	50	0.10646366	0.002129	Prob > F
C. Total	64	0.76665538		<.0001

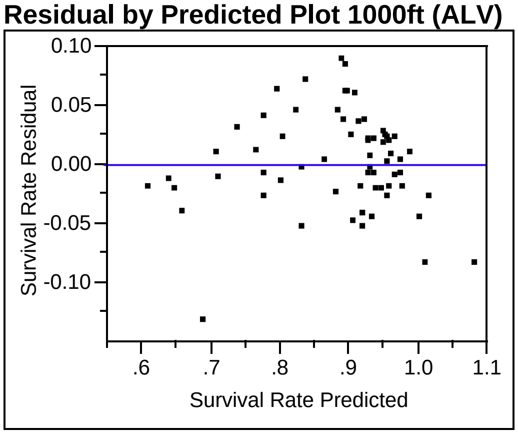
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.8805006	0.029963	29.39	<.0001
UAV Stealth	0.0004936	0.000195	2.53	0.0147
UAV enemy	-0.000064	0.000195	-0.33	0.7428
UAV sns rng	0.0012426	0.000415	3.00	0.0043
UAV speed	0.001189	0.000106	11.20	<.0001
Tank Pk pt1 st1	-0.000315	0.000066	-4.75	<.0001
Tank sns rng st1	-0.001448	0.000648	-2.23	0.0300
ADA_1_ sns rng st4	-0.001502	0.000241	-6.23	<.0001
ADA_1_ Pk st4	-0.000076	0.000013	-5.78	<.0001
(UAV enemy-50.0308)*(UAV speed-117.062)	-0.000014	0.000005	-3.19	0.0024
(UAV sns rng-26.5077)*(Tank sns rng st1-15.0154)	-0.000263	0.000054	-4.85	<.0001
(UAV speed-117.062)*(Tank Pk pt1 st1-152.508)	0.000003	0.000001	2.35	0.0229
(UAV speed-117.062)*(ADA_1_ sns rng st4-40.5077)	0.0000152	0.000005	3.20	0.0024
(Tank Pk pt1 st1-152.508)*(ADA_1_ sns rng st4-40.5077)	-0.000009	0.000004	-2.53	0.0147
(ADA_1_ sns rng st4-40.5077)*(ADA_1_ Pk st4-755.015)	-0.000003	6.575e-7	-5.06	<.0001

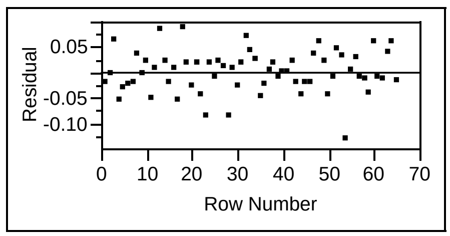
Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
UAV Stealth	1	1	0.01358922	6.3821	0.0147
UAV enemy	1	1	0.00023192	0.1089	0.7428
UAV sns rng	1	1	0.01910690	8.9734	0.0043
UAV speed	1	1	0.26717570	125.4774	<.0001
Tank Pk pt1 st1	1	1	0.04809503	22.5875	<.0001
Tank sns rng st1	1	1	0.01062432	4.9896	0.0300
ADA_1_ sns rng st4	1	1	0.08257426	38.7805	<.0001
ADA_1_ Pk st4	1	1	0.07113918	33.4101	<.0001
UAV enemy*UAV speed	1	1	0.02169529	10.1891	0.0024
UAV sns rng*Tank sns rng st1	1	1	0.05011618	23.5368	<.0001
UAV speed*Tank Pk pt1 st1	1	1	0.01173715	5.5123	0.0229
UAV speed*ADA_1_ sns rng st4	1	1	0.02186492	10.2687	0.0024
Tank Pk pt1 st1*ADA_1_ sns rng st4	1	1	0.01358824	6.3816	0.0147
ADA_1_ sns rng st4*ADA_1_ Pk st4	1	1	0.05458773	25.6368	<.0001

Residual by Predicted Plot 1000ft (ALV)

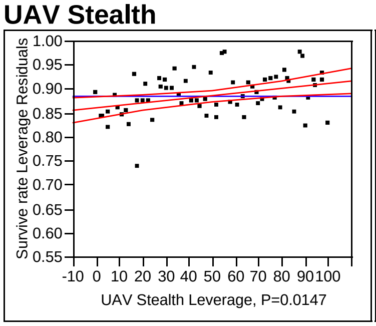


Residual by Row Plot

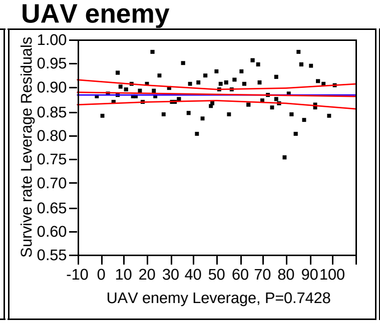


Leverage Plots

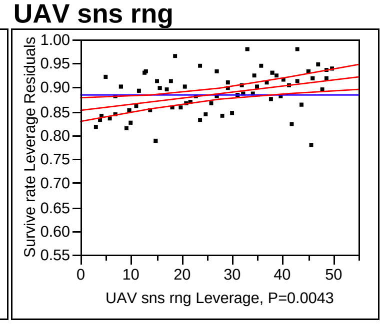
UAV Stealth



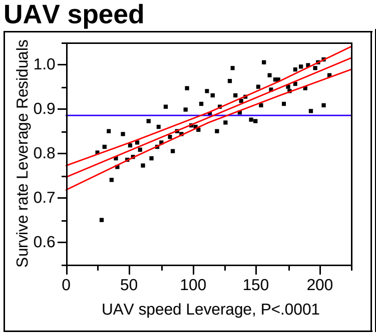
UAV enemy



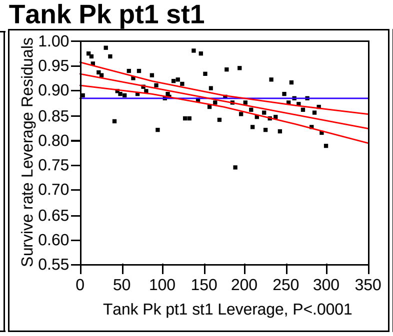
UAV sns rng



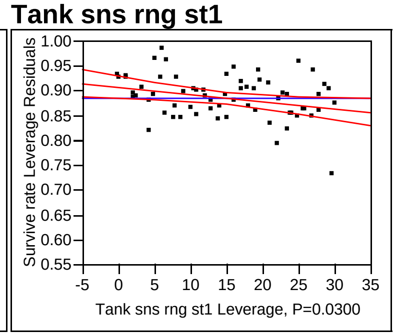
UAV speed



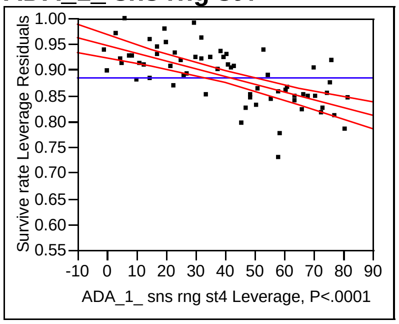
Tank Pk pt1 st1



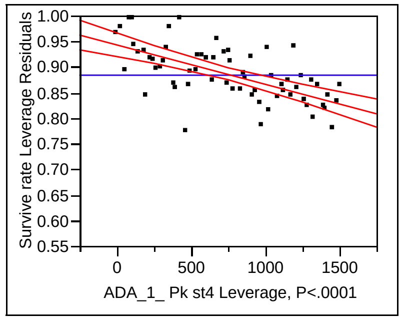
Tank sns rng st1



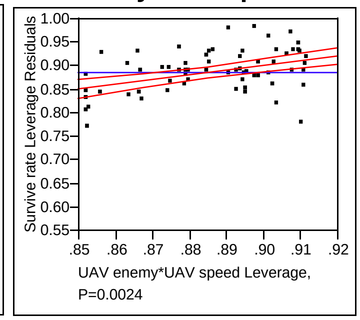
ADA_1_ sns rng st4



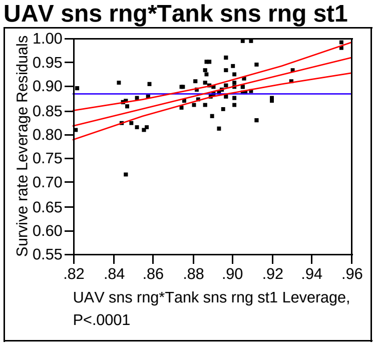
ADA_1_ Pk st4



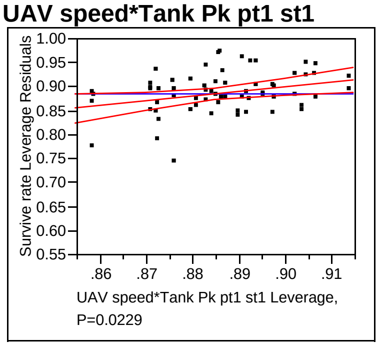
UAV enemy*UAV speed



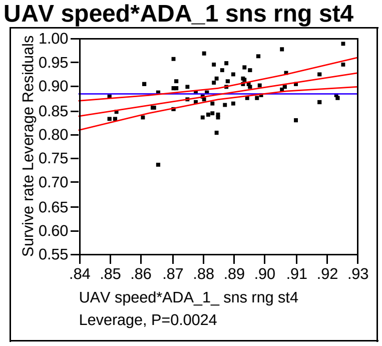
UAV sns rng*Tank sns rng st1



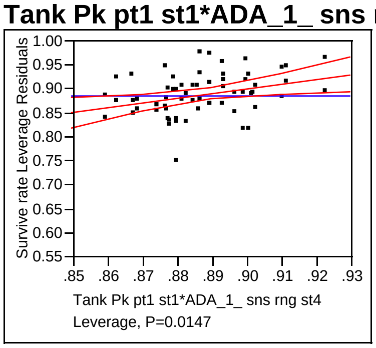
UAV speed*Tank Pk pt1 st1



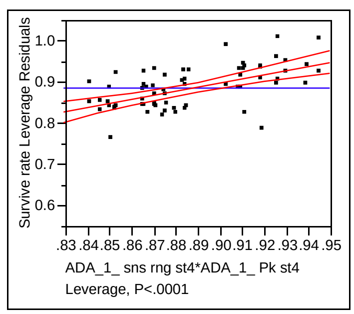
UAV speed*ADA_1 sns rng st4



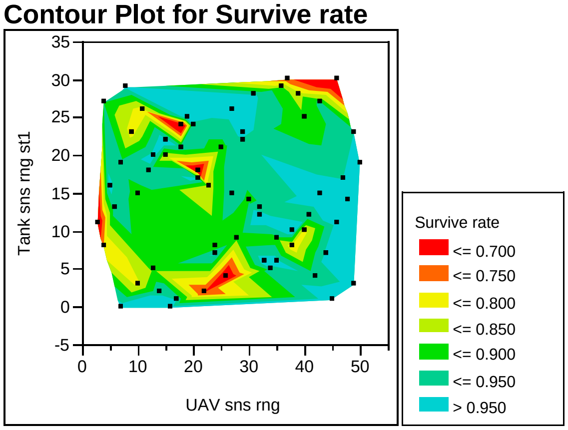
Tank Pk pt1 st1*ADA_1_ sns rng st4



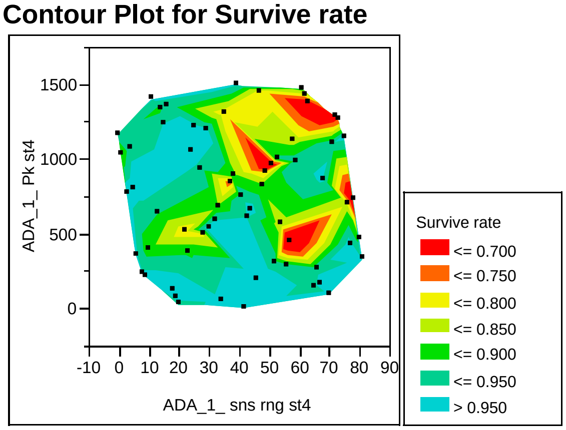
ADA_1_ sns rng st4*ADA_1_ Pk st4



Contour Plot for Survive rate

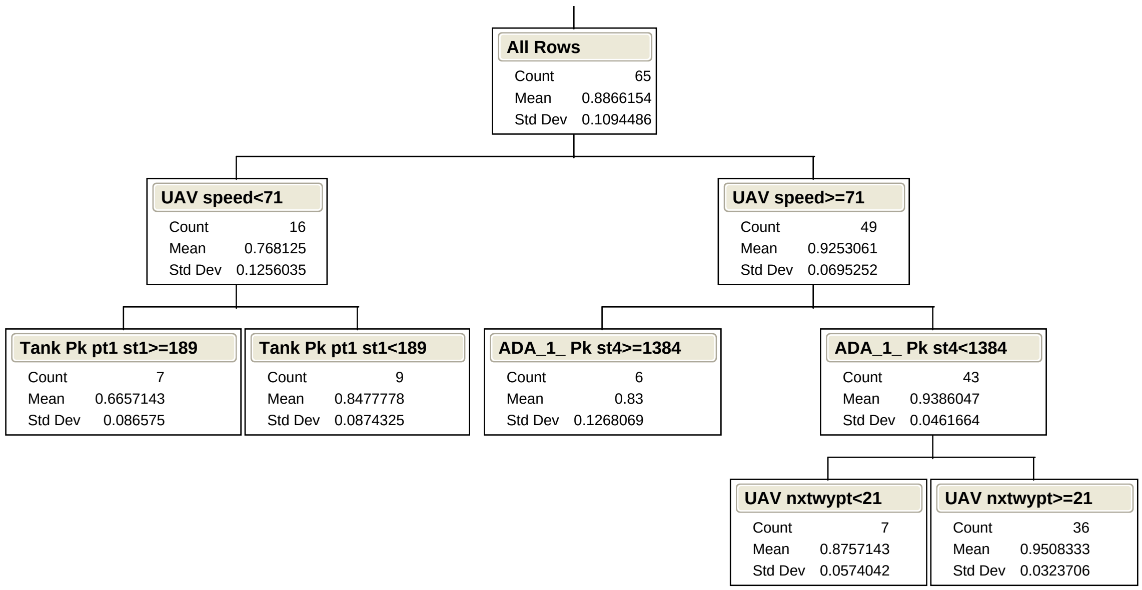


Contour Plot for Survive rate



Partition for Survival Rate

RSquare	N	Imputes
0.683	65	0



Nominal Logistic Fit for Blue survive
Whole Model Test

Model	-LogLikelihood	DF	ChiSquare	Prob>ChiSq
Difference	330.3311	25	660.6623	<.0001
Full	1967.6379			
Reduced	2297.9691			

RSquare (U)	0.1437
Observations (or Sum Wgts)	6500

Converged by Gradient

Lack Of Fit

Source	DF	-LogLikelihood	ChiSquare
Lack Of Fit	39	13.7005	27.40099
Saturated	64	1953.9374	Prob>ChiSq
Fitted	25	1967.6379	0.9184

Parameter Estimates

Term	Estimate	Std Error	ChiSquare	Prob>ChiSq
Intercept	-2.4507075	0.2566202	91.20	<.0001
UAV Stealth	-0.009437	0.0016637	32.18	<.0001
UAV enemy	0.00035211	0.0017956	0.04	0.8445
UAV nxtwypt	0.00122532	0.001814	0.46	0.4994
UAV sns rng	-0.0169734	0.0036027	22.20	<.0001
UAV speed	-0.0129089	0.000908	202.12	<.0001
Tank Pk pt1 st1	0.00306526	0.0006254	24.02	<.0001
Tank sns rng st1	0.02002716	0.0051632	15.05	0.0001
Inf 3 sns rng st1	0.01744283	0.0108558	2.58	0.1081
ADA_1_ sns rng st4	0.01691417	0.0021196	63.68	<.0001
ADA_1_ Pk st4	0.00090015	0.0001229	53.65	<.0001
(UAV enemy-50.0308)*(UAV speed-117.062)	0.00014146	0.0000392	13.00	0.0003
(UAV enemy-50.0308)*(Tank Pk pt1 st1-152.508)	-0.0000991	0.0000309	10.30	0.0013
(UAV enemy-50.0308)*(Inf 3 sns rng st1-9.01538)	0.0003182	0.0004051	0.62	0.4322
(UAV enemy-50.0308)*(ADA_1_ sns rng st4-40.5077)	0.00013169	0.0000531	6.15	0.0131
(UAV nxtwypt-55.0154)*(ADA_1_ sns rng st4-40.5077)	-0.0003207	0.0000819	15.33	<.0001
(UAV sns rng-26.5077)*(Tank sns rng st1-15.0154)	0.00254827	0.0004244	36.06	<.0001

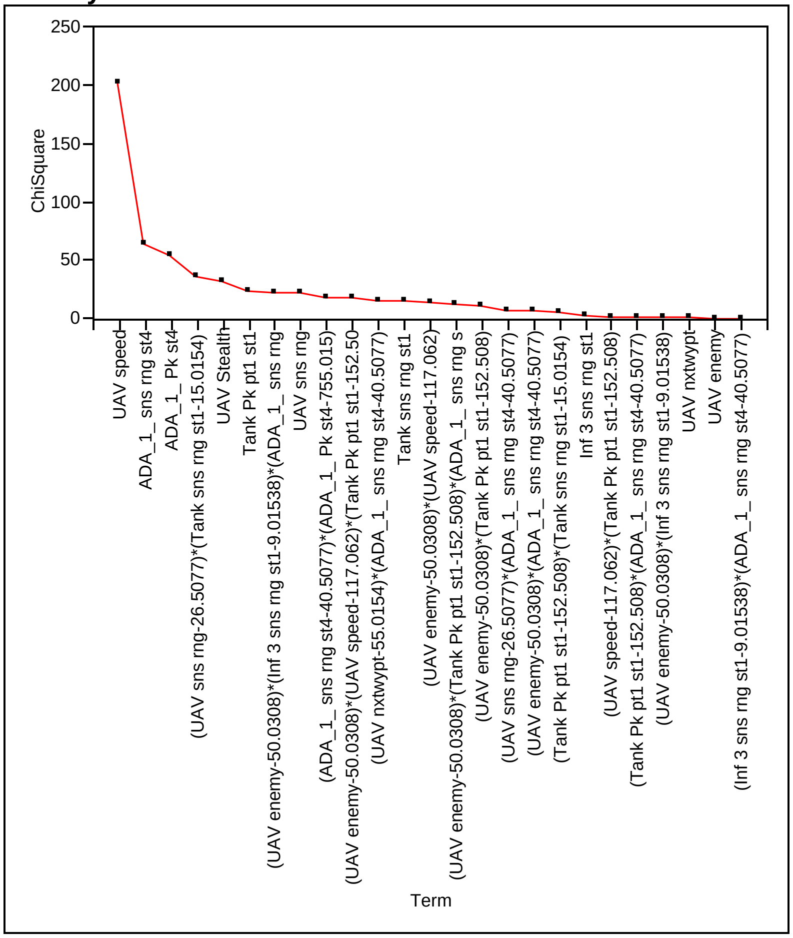
Term	Estimate	Std Error	ChiSquare	Prob>ChiSq
(UAV sns rng-26.5077)*(ADA_1_ sns rng st4-40.5077)	0.00051112	0.0001975	6.70	0.0096
(UAV speed-117.062)*(Tank Pk pt1 st1-152.508)	0.00001613	0.0000122	1.74	0.1876
(Tank Pk pt1 st1-152.508)*(Tank sns rng st1-15.0154)	0.00014787	0.0000609	5.90	0.0151
(Tank Pk pt1 st1-152.508)*(ADA_1_ sns rng st4-40.5077)	-0.0000375	0.0000344	1.19	0.2755
(Inf 3 sns rng st1-9.01538)*(ADA_1_ sns rng st4-40.5077)	-0.0000663	0.0004207	0.02	0.8748
(ADA_1_ sns rng st4-40.5077)*(ADA_1_ Pk st4-755.015)	0.00002624	0.0000061	18.29	<.0001
(UAV enemy-50.0308)*(UAV speed-117.062)*(Tank Pk pt1 st1-152.508)	-0.0000029	7.0079e-7	17.60	<.0001
(UAV enemy-50.0308)*(Tank Pk pt1 st1-152.508)*(ADA_1_ sns rng st4-40.5077)	-0.0000045	0.0000013	12.26	0.0005
(UAV enemy-50.0308)*(Inf 3 sns rng st1-9.01538)*(ADA_1_ sns rng st4-40.5077)	-0.0000641	0.0000135	22.47	<.0001

For log odds of 0/1

Effect Wald Tests

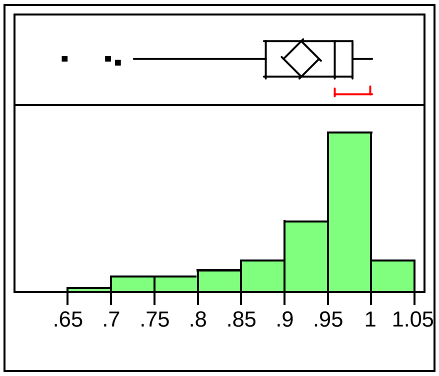
Source	Nparm	DF	Wald ChiSquare	Prob>ChiSq	
UAV Stealth	1	1	32.1754555	0.0000	
UAV enemy	1	1	0.03845225	0.8445	
UAV nxtwypt	1	1	0.45627577	0.4994	
UAV sns rng	1	1	22.1969892	0.0000	
UAV speed	1	1	202.121376	0.0000	
Tank Pk pt1 st1	1	1	24.0234189	0.0000	
Tank sns rng st1	1	1	15.0453941	0.0001	
Inf 3 sns rng st1	1	1	2.58171813	0.1081	
ADA_1_ sns rng st4	1	1	63.6793363	0.0000	
ADA_1_ Pk st4	1	1	53.6501106	0.0000	
UAV enemy*UAV speed	1	1	13.0005804	0.0003	
UAV enemy*Tank Pk pt1 st1	1	1	10.2998533	0.0013	
UAV enemy*Inf 3 sns rng st1	1	1	0.61693641	0.4322	
UAV enemy*ADA_1_ sns rng st4	1	1	6.15017932	0.0131	
UAV nxtwypt*ADA_1_ sns rng st4	1	1	15.3268414	0.0001	
UAV sns rng*Tank sns rng st1	1	1	36.0558333	0.0000	
UAV sns rng*ADA_1_ sns rng st4	1	1	6.69878376	0.0096	
UAV speed*Tank Pk pt1 st1	1	1	1.73632766	0.1876	
Tank Pk pt1 st1*Tank sns rng st1	1	1	5.90113383	0.0151	
Tank Pk pt1 st1*ADA_1_ sns rng st4	1	1	1.1890215	0.2755	
Inf 3 sns rng st1*ADA_1_ sns rng st4	1	1	0.02482049	0.8748	
ADA_1_ sns rng st4*ADA_1_ Pk st4	1	1	18.2898314	0.0000	
UAV enemy*UAV speed*Tank Pk pt1 st1	1	0	0	0.0000	LostDFs
UAV enemy*Tank Pk pt1 st1*ADA_1_ sns rng st4	1	1	12.2596155	0.0005	
UAV enemy*Inf 3 sns rng st1*ADA_1_ sns rng st4	1	1	22.4674204	0.0000	

Overlay Plot



3. 5,000FT ALTITUDE

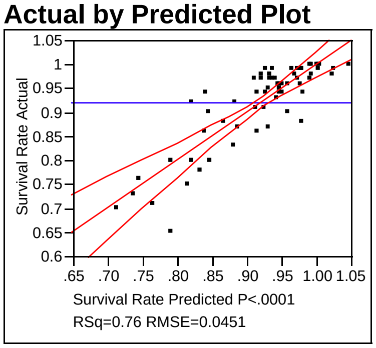
Distributions
Survival Rate



Moments

Mean	0.9206154
Std Dev	0.0863474
Std Err Mean	0.0107101
upper 95% Mean	0.9420112
lower 95% Mean	0.8992196
N	65

Response Survival Rate
Whole Model
Actual by Predicted Plot



Summary of Fit

RSquare	0.75671
RSquare Adj	0.726832
Root Mean Square Error	0.04513
Mean of Response	0.920615
Observations (or Sum Wgts)	65

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	7	0.36108345	0.051583	25.3269
Error	57	0.11609194	0.002037	Prob > F
C. Total	64	0.47717538		<.0001

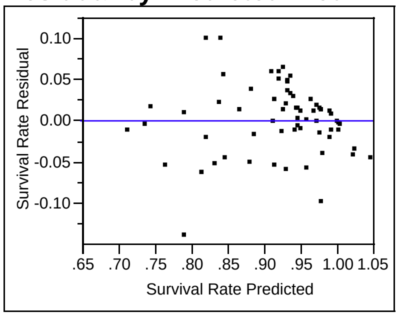
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.9347155	0.02402	38.91	<.0001
UAV sns rng	0.0010563	0.000406	2.60	0.0117
UAV speed	0.00086	0.000104	8.28	<.0001
Tank Pk pt1 st1	-0.000245	0.000065	-3.78	0.0004
ADA_1_ sns rng st4	-0.001532	0.000236	-6.49	<.0001
ADA_1_ Pk st4	-0.000058	0.000013	-4.50	<.0001
(UAV speed-117.062)*(ADA_1_ sns rng st4-40.5077)	0.0000163	0.000004	3.71	0.0005
(ADA_1_ sns rng st4-40.5077)*(ADA_1_ Pk st4-755.015)	-0.000002	5.599e-7	-3.22	0.0021

Effect Tests - 5000ft Altitude

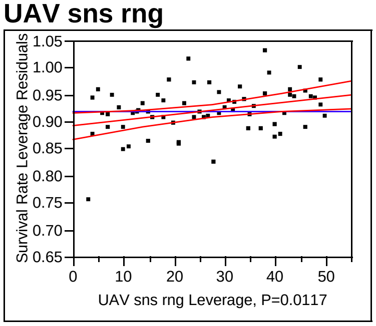
Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
UAV sns rng	1	1	0.01380867	6.7799	0.0117
UAV speed	1	1	0.13977423	68.6278	<.0001
Tank Pk pt1 st1	1	1	0.02913318	14.3041	0.0004
ADA_1_ sns rng st4	1	1	0.08587559	42.1641	<.0001
ADA_1_ Pk st4	1	1	0.04125264	20.2546	<.0001
UAV speed*ADA_1_ sns rng st4	1	1	0.02806648	13.7804	0.0005
ADA_1_ sns rng st4*ADA_1_ Pk st4	1	1	0.02113412	10.3766	0.0021

Residual by Predicted Plot

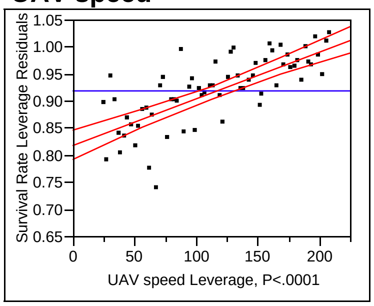


Leverage Plot

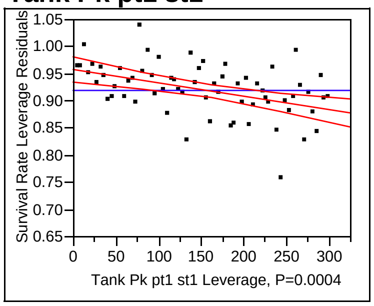
UAV sns rng



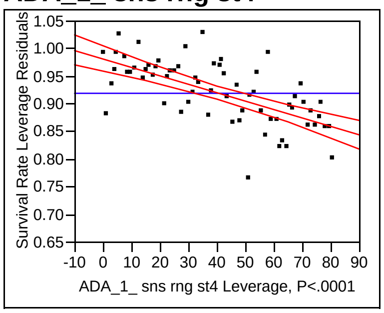
UAV speed



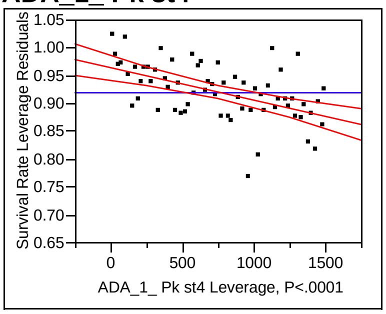
Tank Pk pt1 st1



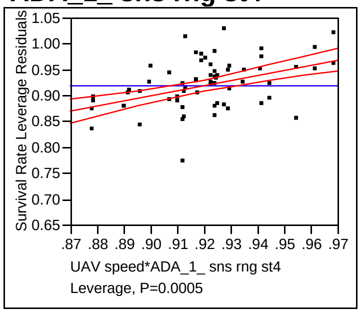
ADA_1_ sns rng st4



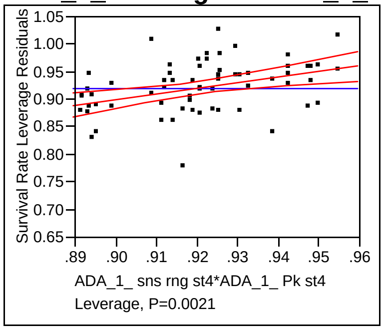
ADA_1_ Pk st4



**UAV speed*
ADA_1_ sns rng st4**



ADA_1_ sns rng st4*ADA_1_ Pk st4

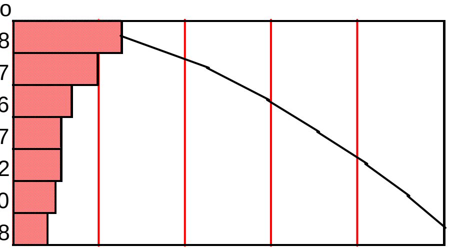


Effect Screening

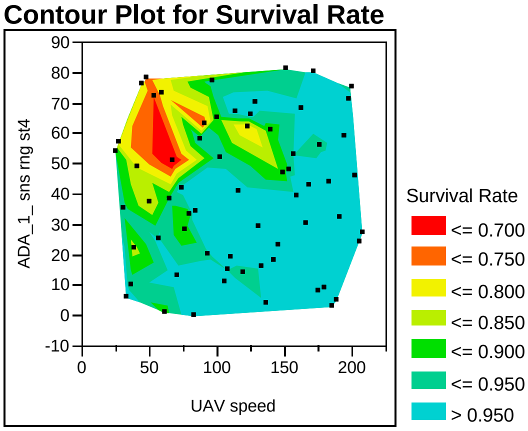
	Lenth PSE
t-Test Scale	5.8386066
Coded Scale	0.0326826

Pareto Plot of Estimates

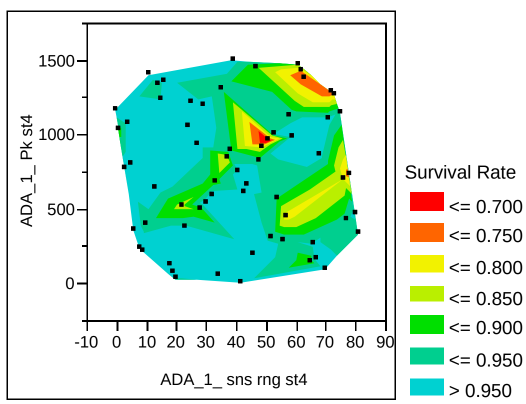
Term	t Ratio
UAV speed	8.284188
ADA_1_ sns rng st4	-6.493387
ADA_1_ Pk st4	-4.500516
Tank Pk pt1 st1	-3.782077
(UAV speed-117.062)*(ADA_1_ sns rng st4-40.5077)	3.712192
(ADA_1_ sns rng st4-40.5077)*(ADA_1_ Pk st4-755.015)	-3.221280
UAV sns rng	2.603828



Contour Plot for Survival Rate

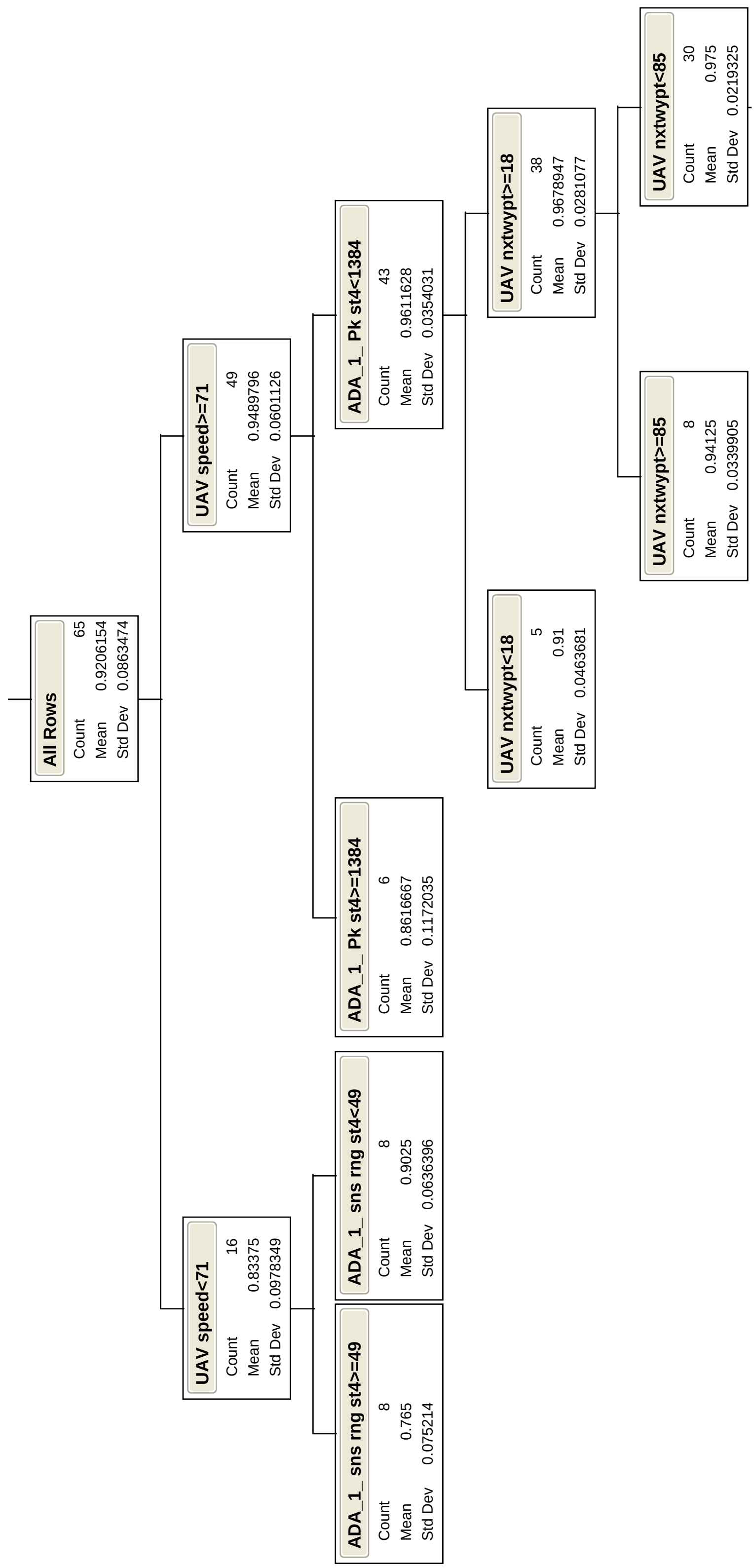


Contour Plot for Survival Rate



Partition for Survival Rate

RSquare	N	Imputes
0.663	65	0



Nominal Logistic Fit for Blue survive

Whole Model Test

Model	-LogLikelihood	DF	ChiSquare	Prob>ChiSq
Difference	273.0698	23	546.1397	<.0001
Full	1529.1449			
Reduced	1802.2148			

RSquare (U)	0.1515
Observations (or Sum Wgts)	6500

Converged by Objective

Lack Of Fit

Source	DF	-LogLikelihood	ChiSquare
Lack Of Fit	41	23.3342	46.66831
Saturated	64	1505.8108	Prob>ChiSq
Fitted	23	1529.1449	0.2507

Parameter Estimates

Term	Estimate	Std Error	ChiSquare	Prob>ChiSq
Intercept	-4.4224493	0.3730334	140.55	<.0001
UAV Stealth	-0.0027546	0.0019123	2.08	0.1497
UAV nxtwypt	0.00742164	0.0021729	11.67	0.0006
UAV sns rng	-0.0066808	0.0047047	2.02	0.1556
UAV speed	-0.0157447	0.0012681	154.16	<.0001
Tank Pk pt1 st1	0.00643611	0.0007988	64.92	<.0001
Tank sns rng st1	0.01214223	0.0068916	3.10	0.0781
ADA_1_ sns rng st4	0.02729128	0.0025704	112.73	<.0001
ADA_1_ Pk st4	0.00090232	0.0001487	36.84	<.0001
(UAV Stealth-50.0308)*(Tank Pk pt1 st1-152.508)	0.00000266	0.0000222	0.01	0.9047
(UAV Stealth-50.0308)*(ADA_1_ Pk st4-755.015)	0.00000817	0.0000068	1.46	0.2267
(UAV nxtwypt-55.0154)*(UAV sns rng-26.5077)	-0.0003415	0.0002184	2.44	0.1180
(UAV nxtwypt-55.0154)*(Tank sns rng st1-15.0154)	-0.0000677	0.000331	0.04	0.8380
(UAV nxtwypt-55.0154)*(ADA_1_ sns rng st4-40.5077)	-0.0000311	0.0000985	0.10	0.7524
(UAV sns rng-26.5077)*(UAV speed-117.062)	0.00027318	0.0000828	10.89	0.0010
(UAV sns rng-26.5077)*(Tank sns rng st1-15.0154)	0.00133025	0.000495	7.22	0.0072
(UAV sns rng-26.5077)*(ADA_1_ sns rng st4-40.5077)	0.00041974	0.0002408	3.04	0.0813
(Tank Pk pt1 st1-152.508)*(ADA_1_ Pk st4-755.015)	-0.0000041	0.0000019	4.64	0.0312
(Tank sns rng st1-15.0154)*(ADA_1_ sns rng st4-40.5077)	0.00019565	0.0003236	0.37	0.5455
(UAV Stealth-50.0308)*(Tank Pk pt1 st1-152.508)*(ADA_1_ Pk st4-755.015)	1.82131e-7	5.7956e-8	9.88	0.0017
(UAV nxtwypt-55.0154)*(UAV sns rng-26.5077)*(Tank sns rng st1-15.0154)	-0.0001325	0.0000281	22.30	<.0001
(UAV nxtwypt-55.0154)*(UAV sns rng-26.5077)*(ADA_1_ sns rng st4-40.5077)	-0.0000317	0.0000085	13.98	0.0002
(UAV nxtwypt-55.0154)*(Tank sns rng st1-15.0154)*(ADA_1_ sns rng st4-40.5077)	0.00003093	0.0000127	5.94	0.0148
(UAV nxtwypt-55.0154)*(UAV nxtwypt-55.0154)	0.00024531	0.0001063	5.33	0.0210

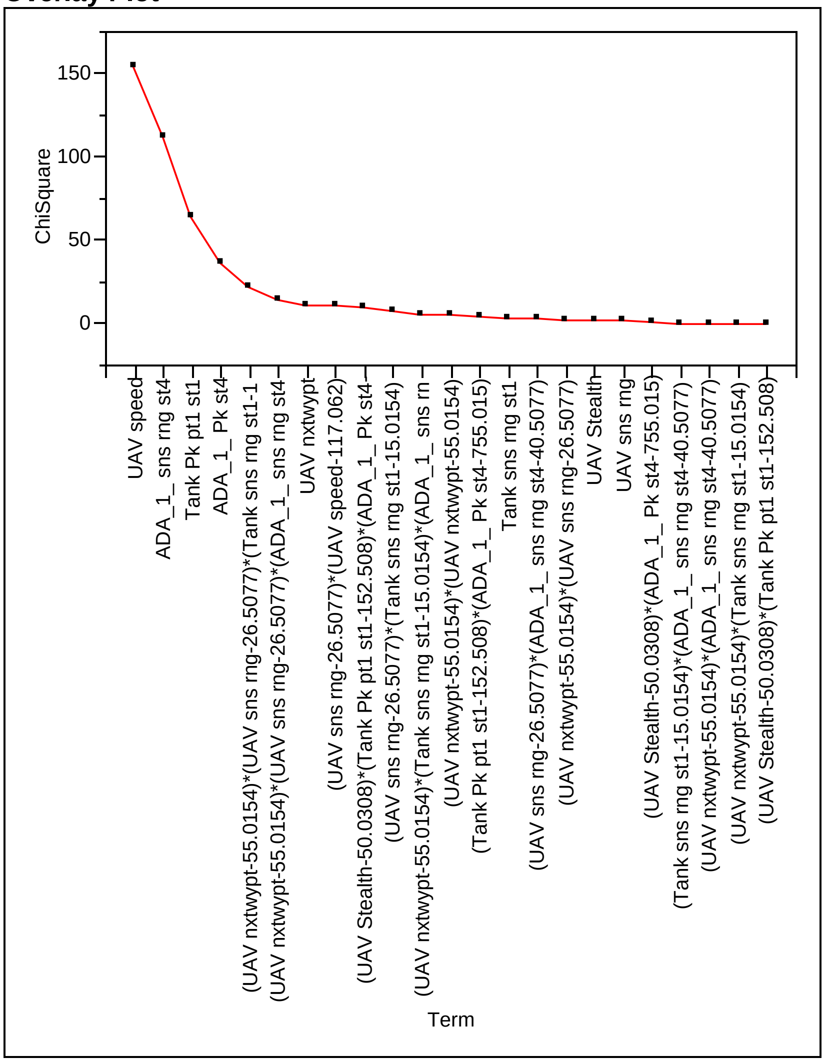
For log odds of 0/1

Effect Wald Tests

Source	Nparm	DF	Wald ChiSquare	Prob>ChiSq	
UAV Stealth	1	1	2.07504178	0.1497	
UAV nxtwypt	1	1	11.6659137	0.0006	
UAV sns rng	1	1	2.01646421	0.1556	
UAV speed	1	1	154.162988	0.0000	
Tank Pk pt1 st1	1	1	64.9199598	0.0000	
Tank sns rng st1	1	1	3.1042412	0.0781	
ADA_1_ sns rng st4	1	1	112.73316	0.0000	
ADA_1_ Pk st4	1	1	36.8394967	0.0000	
UAV Stealth*Tank Pk pt1 st1	1	1	0.01433077	0.9047	
UAV Stealth*ADA_1_ Pk st4	1	1	1.46157474	0.2267	
UAV nxtwypt*UAV sns rng	1	1	2.44432412	0.1180	
UAV nxtwypt*Tank sns rng st1	1	1	0.04182183	0.8380	
UAV nxtwypt*ADA_1_ sns rng st4	1	1	0.09952633	0.7524	
UAV sns rng*UAV speed	1	1	10.8879712	0.0010	
UAV sns rng*Tank sns rng st1	1	1	7.2234544	0.0072	
UAV sns rng*ADA_1_ sns rng st4	1	1	3.03955017	0.0813	
Tank Pk pt1 st1*ADA_1_ Pk st4	1	1	4.64355856	0.0312	

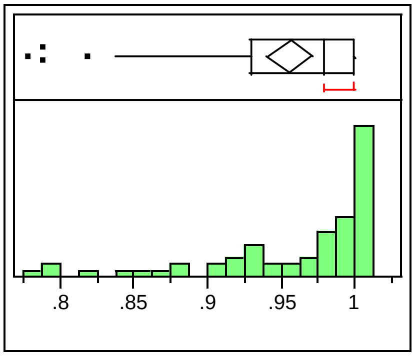
Source	Nparm	DF	Wald ChiSquare	Prob>ChiSq	
Tank sns rng st1*ADA_1_ sns rng st4	1	1	0.36545653	0.5455	
UAV Stealth*Tank Pk pt1 st1*ADA_1_ Pk st4	1	0	0	0.0000	LostDFs
UAV nxtwypt*UAV sns rng*Tank sns rng st1	1	1	22.3023966	0.0000	
UAV nxtwypt*UAV sns rng*ADA_1_ sns rng st4	1	1	13.9763163	0.0002	
UAV nxtwypt*Tank sns rng st1*ADA_1_ sns rng st4	1	1	5.94281323	0.0148	
UAV nxtwypt*UAV nxtwypt	1	1	5.32543763	0.0210	

Overlay Plot



4. 10,000FT ALTITUDE

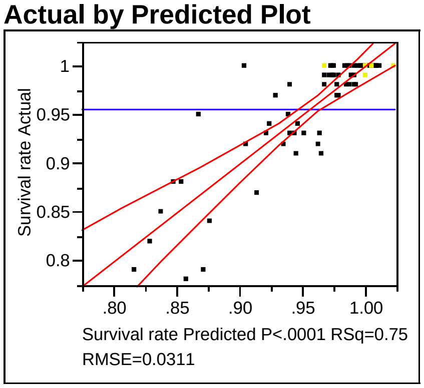
Distributions
Survival Rate



Moments

Mean	0.9567692
Std Dev	0.0586064
Std Err Mean	0.0072692
upper 95% Mean	0.9712912
lower 95% Mean	0.9422473
N	65

Response Survival rate
Whole Model
Actual by Predicted Plot



Summary of Fit

RSquare	0.753293
RSquare Adj	0.718049
Root Mean Square Error	0.031119
Mean of Response	0.956769
Observations (or Sum Wgts)	65

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	8	0.16559007	0.020699	21.3738
Error	56	0.05423147	0.000968	Prob > F
C. Total	64	0.21982154		<.0001

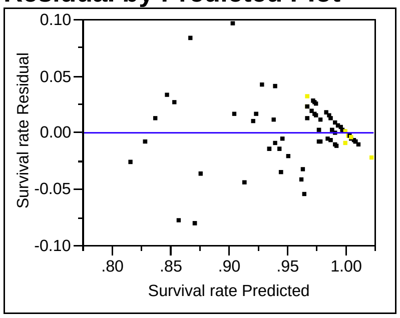
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	1.0097442	0.015319	65.91	<.0001
UAV Stealth	-0.000447	0.000132	-3.39	0.0013
UAV speed	0.0004777	0.000072	6.67	<.0001
ADA_1_ sns rng st4	-0.00114	0.000163	-7.01	<.0001
ADA_1_ Pk st4	-0.000038	0.000009	-4.31	<.0001
(UAV Stealth-50.0308)*(ADA_1_ Pk st4-755.015)	-8.961e-7	2.982e-7	-3.00	0.0040
(UAV speed-117.062)*(ADA_1_ sns rng st4-40.5077)	0.0000144	0.000003	4.74	<.0001
(ADA_1_ sns rng st4-40.5077)*(ADA_1_ Pk st4-755.015)	-0.000001	3.953e-7	-2.68	0.0095
(UAV speed-117.062)*(UAV speed-117.062)	-0.000004	0.000002	-2.62	0.0112

Effect Tests - 10,000ft Altitude

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
UAV Stealth	1	1	0.01115033	11.5140	0.0013
UAV speed	1	1	0.04312951	44.5360	<.0001
ADA_1_ sns rng st4	1	1	0.04753680	49.0870	<.0001
ADA_1_ Pk st4	1	1	0.01799735	18.5843	<.0001
UAV Stealth*ADA_1_ Pk st4	1	1	0.00874321	9.0283	0.0040
UAV speed*ADA_1_ sns rng st4	1	1	0.02174887	22.4581	<.0001
ADA_1_ sns rng st4*ADA_1_ Pk st4	1	1	0.00697975	7.2074	0.0095
UAV speed*UAV speed	1	1	0.00666616	6.8835	0.0112

Residual by Predicted Plot

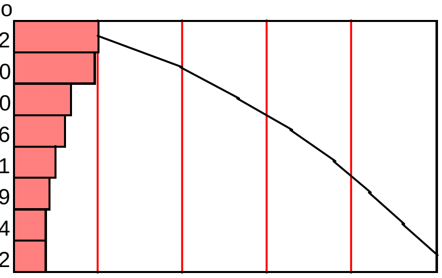


Effect Screening

	Lenth PSE
t-Test Scale	5.8290448
Coded Scale	0.0224995

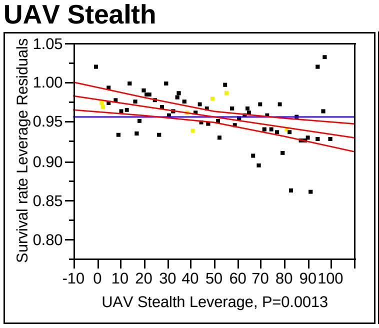
Pareto Plot of Estimates

Term	t Ratio
ADA_1_ sns rng st4	-7.006212
UAV speed	6.673530
(UAV speed-117.062)*(ADA_1_ sns rng st4-40.5077)	4.739000
ADA_1_ Pk st4	-4.310946
UAV Stealth	-3.393221
(UAV Stealth-50.0308)*(ADA_1_ Pk st4-755.015)	-3.004719
(ADA_1_ sns rng st4-40.5077)*(ADA_1_ Pk st4-755.015)	-2.684654
(UAV speed-117.062)*(UAV speed-117.062)	-2.623652

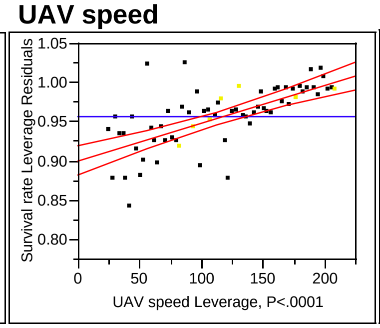


Leverage Plots

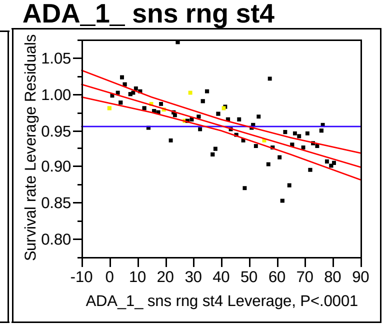
UAV Stealth



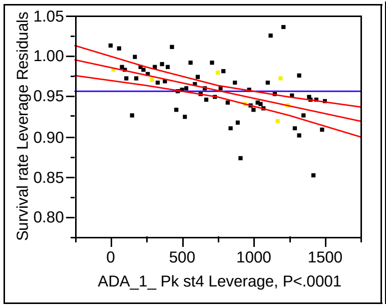
UAV speed



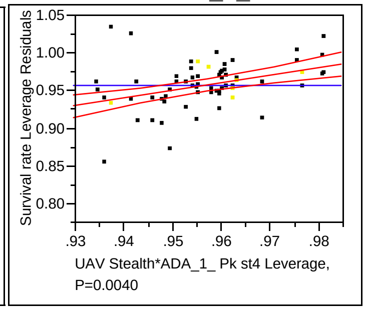
ADA_1_ sns rng st4



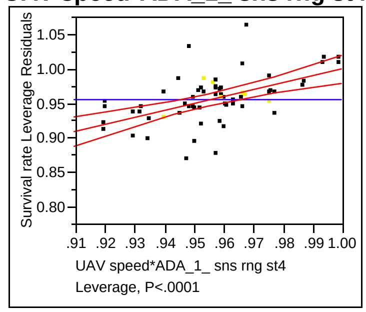
ADA_1_ Pk st4



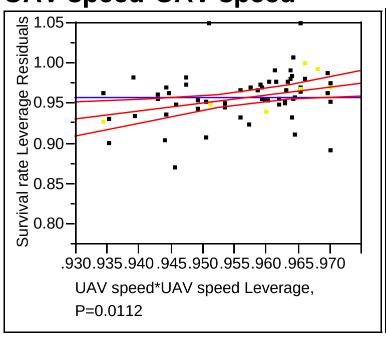
UAV Stealth*ADA_1_ Pk st4



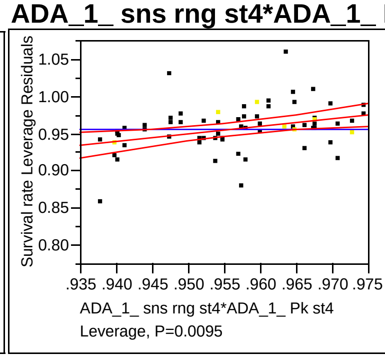
UAV speed*ADA_1_ sns rng st4



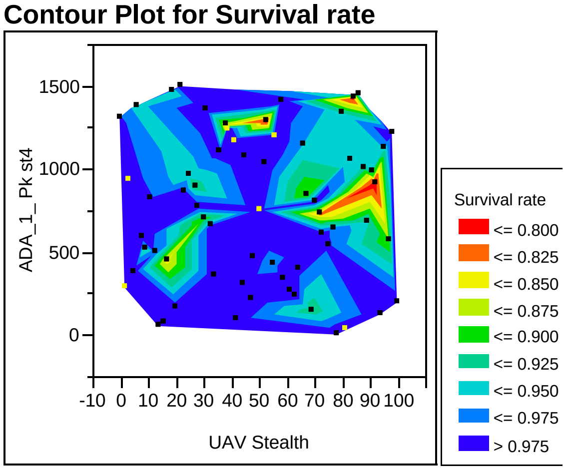
UAV speed*UAV speed



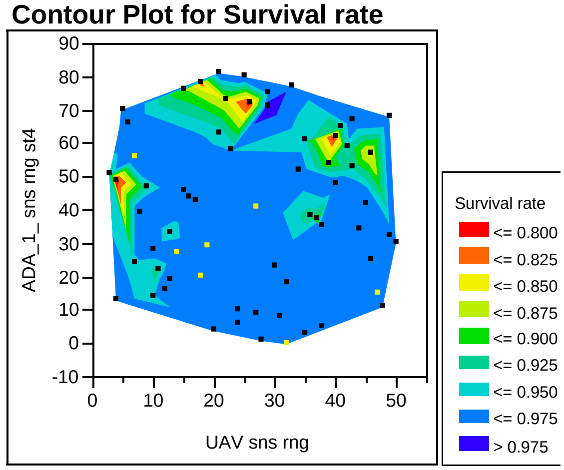
ADA_1_ sns rng st4*ADA_1_ Pk st4



Contour Plot for Survival rate

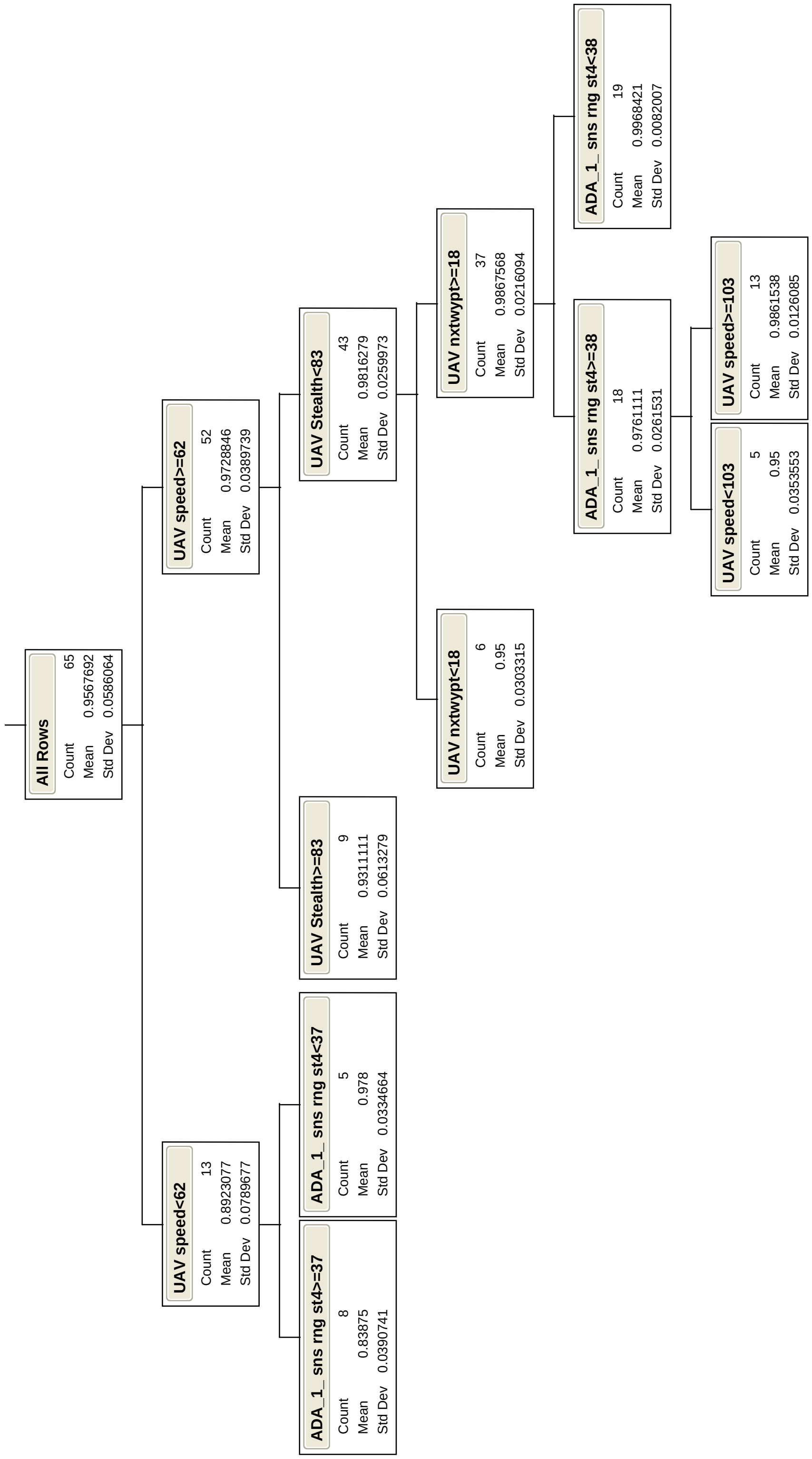


Contour Plot for Survival rate



Partition for Survival rate

RSquare	N	Imputes
0.736	65	0



Nominal Logistic Fit for Blue survive

Whole Model Test

Model	-LogLikelihood	DF	ChiSquare	Prob>ChiSq
Difference	218.9116	23	437.8232	<.0001
Full	938.6030			
Reduced	1157.5146			

RSquare (U)	0.1891
Observations (or Sum Wgts)	6500

Converged by Gradient

Lack Of Fit

Source	DF	-LogLikelihood	ChiSquare
Lack Of Fit	41	22.21412	44.42824
Saturated	64	916.38886	Prob>ChiSq
Fitted	23	938.60298	0.3293

Parameter Estimates

Term	Estimate	Std Error	ChiSquare	Prob>ChiSq
Intercept	-4.3802585	0.4693649	87.09	<.0001
UAV Stealth	0.01265099	0.0040301	9.85	0.0017
UAV enemy	0.00437438	0.004065	1.16	0.2819
UAV nxtwypt	-0.0121336	0.0058373	4.32	0.0377
UAV sns rng	-0.0195603	0.0074158	6.96	0.0083
UAV speed	-0.0202494	0.0025498	63.07	<.0001
ADA_1_ sns rng st4	0.06248496	0.0099487	39.45	<.0001
ADA_1_ Pk st4	0.00150333	0.0003145	22.85	<.0001
(UAV Stealth-50.0308)*(UAV speed-117.062)	0.00028214	0.0000608	21.53	<.0001
(UAV enemy-50.0308)*(UAV nxtwypt-55.0154)	0.00033674	0.0001076	9.79	0.0018
(UAV enemy-50.0308)*(UAV sns rng-26.5077)	-0.0015209	0.000568	7.17	0.0074
(UAV enemy-50.0308)*(UAV speed-117.062)	0.00033194	0.0000859	14.92	0.0001
(UAV enemy-50.0308)*(ADA_1_ Pk st4-755.015)	-0.0000211	0.0000076	7.76	0.0053
(UAV nxtwypt-55.0154)*(UAV sns rng-26.5077)	0.00091061	0.0003415	7.11	0.0077
(UAV nxtwypt-55.0154)*(UAV speed-117.062)	-0.0006973	0.0001921	13.18	0.0003
(UAV nxtwypt-55.0154)*(ADA_1_ sns rng st4-40.5077)	0.000327	0.0002461	1.77	0.1839
(UAV sns rng-26.5077)*(ADA_1_ sns rng st4-40.5077)	0.00251975	0.0005102	24.39	<.0001
(UAV speed-117.062)*(ADA_1_ sns rng st4-40.5077)	-0.0001532	0.000106	2.09	0.1482
(UAV speed-117.062)*(ADA_1_ Pk st4-755.015)	0.00000771	0.0000086	0.80	0.3713
(UAV enemy-50.0308)*(UAV speed-117.062)*(ADA_1_ Pk st4-755.015)	-0.0000012	2.7941e-7	17.91	<.0001
(UAV nxtwypt-55.0154)*(UAV speed-117.062)*(ADA_1_ sns rng st4-40.5077)	0.00002255	0.0000064	12.57	0.0004
(UAV speed-117.062)*(UAV speed-117.062)	0.00011307	0.000052	4.72	0.0298
(ADA_1_ sns rng st4-40.5077)*(ADA_1_ sns rng st4-40.5077)	-0.0019205	0.0003593	28.56	<.0001
(ADA_1_ Pk st4-755.015)*(ADA_1_ Pk st4-755.015)	-0.0000031	8.8911e-7	12.25	0.0005

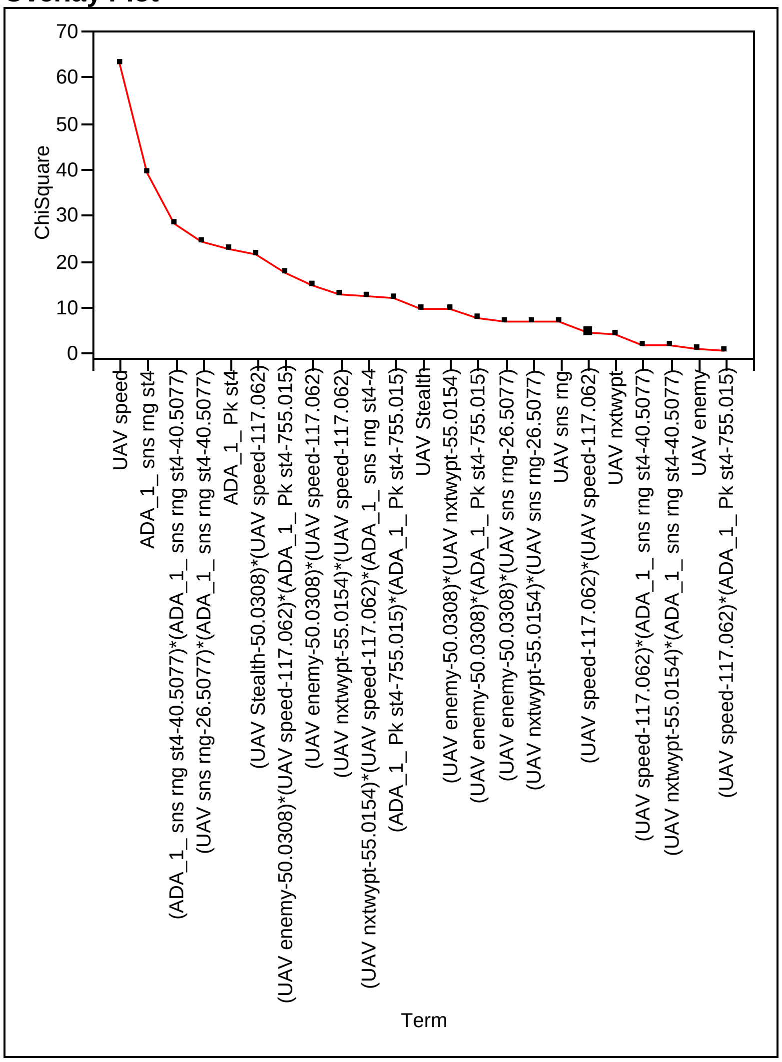
For log odds of 0/1

Effect Wald Tests

Source	Nparm	DF	Wald ChiSquare	Prob>ChiSq	
UAV Stealth	1	1	9.85411954	0.0017	
UAV enemy	1	1	1.15800586	0.2819	
UAV nxtwypt	1	1	4.32073233	0.0377	
UAV sns rng	1	1	6.95730123	0.0083	
UAV speed	1	1	63.0684907	0.0000	
ADA_1_ sns rng st4	1	1	39.4471146	0.0000	
ADA_1_ Pk st4	1	1	22.8465429	0.0000	
UAV Stealth*UAV speed	1	1	21.5251776	0.0000	
UAV enemy*UAV nxtwypt	1	1	9.79456445	0.0018	
UAV enemy*UAV sns rng	1	1	7.17087834	0.0074	
UAV enemy*UAV speed	1	1	14.9181227	0.0001	
UAV enemy*ADA_1_ Pk st4	1	1	7.76395188	0.0053	
UAV nxtwypt*UAV sns rng	1	1	7.1086711	0.0077	
UAV nxtwypt*UAV speed	1	1	13.1813249	0.0003	
UAV nxtwypt*ADA_1_ sns rng st4	1	1	1.76543141	0.1839	
UAV sns rng*ADA_1_ sns rng st4	1	1	24.3945489	0.0000	
UAV speed*ADA_1_ sns rng st4	1	1	2.09042717	0.1482	
UAV speed*ADA_1_ Pk st4	1	1	0.79929698	0.3713	

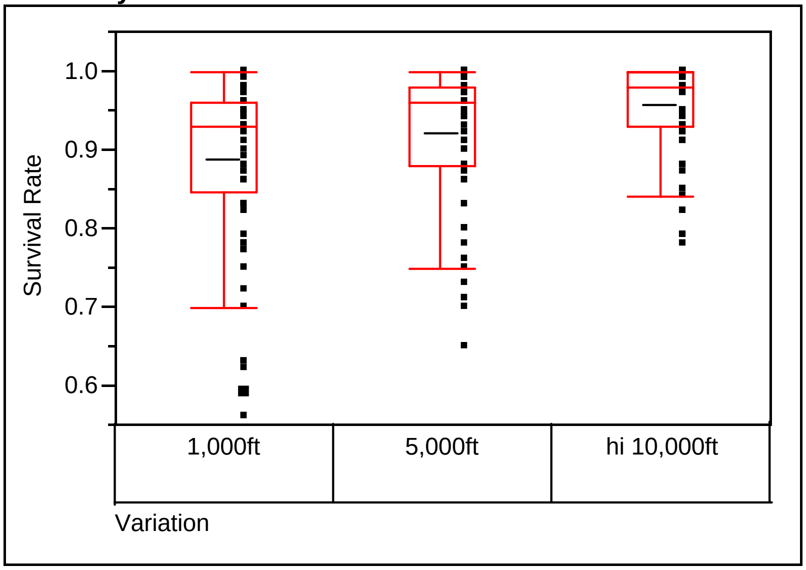
Source	Nparm	DF	Wald ChiSquare	Prob>ChiSq	
UAV enemy*UAV speed*ADA_1_ Pk st4	1	0	0	0.0000	LostDFs
UAV nxtwypt*UAV speed*ADA_1_ sns rng st4	1	1	12.5738983	0.0004	
UAV speed*UAV speed	1	1	4.72009556	0.0298	
ADA_1_ sns rng st4*ADA_1_ sns rng st4	1	1	28.5640532	0.0000	
ADA_1_ Pk st4*ADA_1_ Pk st4	1	0	0	0.0000	LostDFs

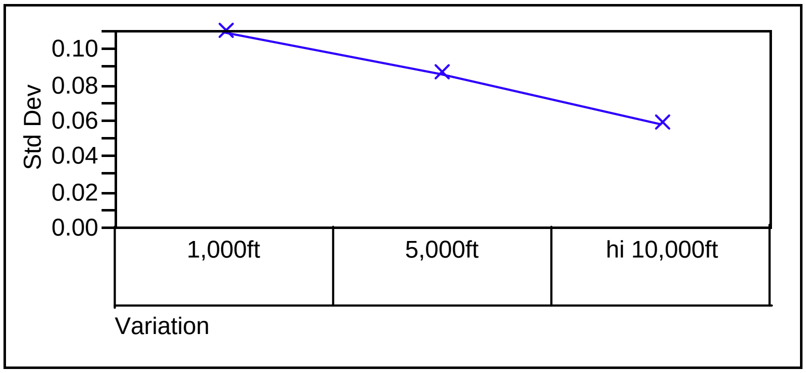
Overlay Plot



5. ALTITUDE SUMMARY

Variability Chart for Survival Rate





Analysis of Variance

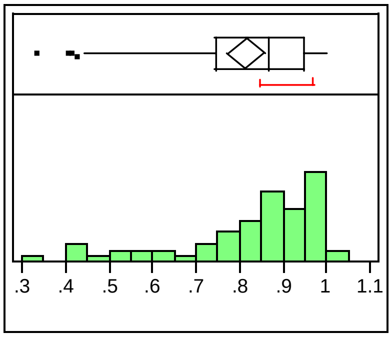
Source	DF	SS	Mean Square	F Ratio	Prob > F
Variation	2	0.160001	0.08	10.4944	<.0001
Within	192	1.463652	0.00762		
Total	194	1.623653	0.00837		

Variance Components

Component	Var Component	% of Total	Plot%	Sqrt(Var Comp)
Variation	0.00111350	12.7		0.03337
Within	0.00762319	87.3		0.08731
Total	0.00873669	100.0		0.09347

6. Alternate Tactical Layout 1

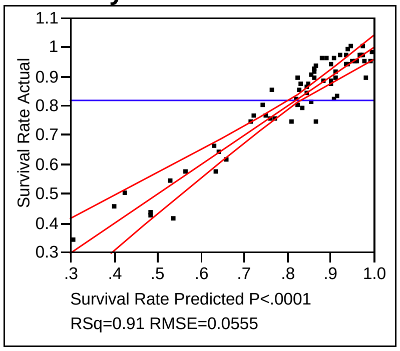
Distributions
Survival Rate



Moments

Mean	0.8175385
Std Dev	0.1679009
Std Err Mean	0.0208255
upper 95% Mean	0.8591423
lower 95% Mean	0.7759346
N	65

Response Survival Rate
Actual by Predicted Plot



Summary of Fit

RSquare	0.914633
RSquare Adj	0.890731
Root Mean Square Error	0.055501
Mean of Response	0.817538
Observations (or Sum Wgts)	65

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	14	1.6501872	0.117871	38.2649
Error	50	0.1540190	0.003080	Prob > F
C. Total	64	1.8042062		<.0001

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.8190034	0.031386	26.09	<.0001
UAV Stealth	0.0024689	0.000235	10.51	<.0001
UAV speed	0.0013921	0.000128	10.90	<.0001
Tank Pk pt1 st1	-0.000254	0.00008	-3.19	0.0025
Inf _3_ Pk pt1 st1	-0.001809	0.000808	-2.24	0.0297
ADA_1_ sns rng st4	-0.003097	0.00029	-10.67	<.0001
ADA_1_ Pk st4	-0.000128	0.000016	-8.09	<.0001
(UAV Stealth-50.0308)*(UAV speed-117.062)	-0.000014	0.000004	-3.52	0.0009
(UAV Stealth-50.0308)*(ADA_1_ Pk st4-755.015)	0.0000017	5.39e-7	3.18	0.0025
(UAV speed-117.062)*(Inf _3_ Pk pt1 st1-15.5077)	0.0000459	0.000014	3.27	0.0020
(UAV speed-117.062)*(ADA_1_ sns rng st4-40.5077)	0.0000159	0.000006	2.77	0.0078
(UAV speed-117.062)*(ADA_1_ Pk st4-755.015)	0.0000011	3.8e-7	2.86	0.0062
(Tank Pk pt1 st1-152.508)*(Inf _3_ Pk pt1 st1-15.5077)	-0.00005	0.000012	-4.13	0.0001
(Inf _3_ Pk pt1 st1-15.5077)*(ADA_1_ Pk st4-755.015)	0.0000043	0.000002	2.16	0.0356
(ADA_1_ sns rng st4-40.5077)*(ADA_1_ Pk st4-755.015)	-0.000004	7.262e-7	-5.25	<.0001

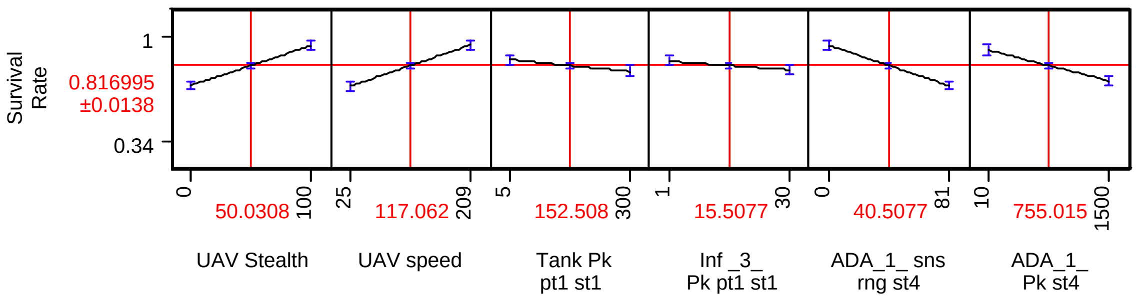
Effect Tests Alternate Tactical 1

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
UAV Stealth	1	1	0.34005726	110.3946	<.0001
UAV speed	1	1	0.36625149	118.8982	<.0001
Tank Pk pt1 st1	1	1	0.03135504	10.1790	0.0025
Inf _3_ Pk pt1 st1	1	1	0.01543678	5.0113	0.0297
ADA_1_ sns rng st4	1	1	0.35090140	113.9150	<.0001
ADA_1_ Pk st4	1	1	0.20157198	65.4374	<.0001
UAV Stealth*UAV speed	1	1	0.03824057	12.4142	0.0009
UAV Stealth*ADA_1_ Pk st4	1	1	0.03113453	10.1074	0.0025
UAV speed*Inf _3_ Pk pt1 st1	1	1	0.03285973	10.6674	0.0020
UAV speed*ADA_1_ sns rng st4	1	1	0.02369136	7.6911	0.0078
UAV speed*ADA_1_ Pk st4	1	1	0.02517618	8.1731	0.0062
Tank Pk pt1 st1*Inf _3_ Pk pt1 st1	1	1	0.05260743	17.0782	0.0001
Inf _3_ Pk pt1 st1*ADA_1_ Pk st4	1	1	0.01436883	4.6646	0.0356
ADA_1_ sns rng st4*ADA_1_ Pk st4	1	1	0.08481969	27.5355	<.0001

Scaled Estimates

Continuous factors centered by mean, scaled by range/2

Prediction Profiler

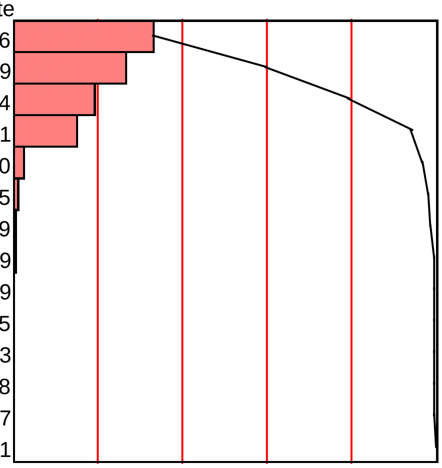


Effect Screening

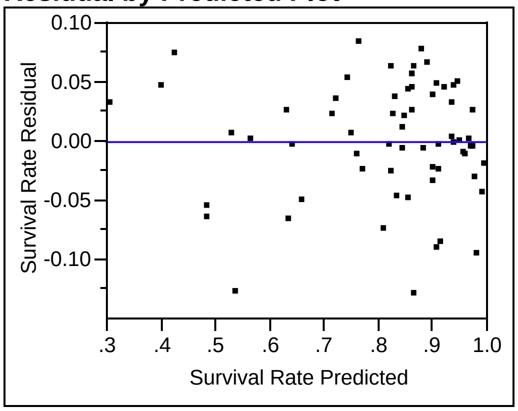
	Lenth PSE
t-Test Scale	6.4173645
Coded Scale	0.0441776

Pareto Plot of Estimates

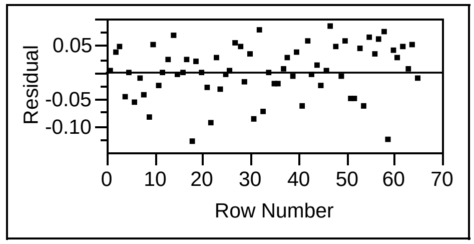
Term	Estimate
ADA_1_ sns rng st4	-0.0030966
UAV Stealth	0.0024689
Inf _3_ Pk pt1 st1	-0.0018094
UAV speed	0.0013921
Tank Pk pt1 st1	-0.0002540
ADA_1_ Pk st4	-0.0001275
(Tank Pk pt1 st1-152.508)*(Inf _3_ Pk pt1 st1-15.5077)	-0.0000499
(UAV speed-117.062)*(Inf _3_ Pk pt1 st1-15.5077)	0.0000459
(UAV speed-117.062)*(ADA_1_ sns rng st4-40.5077)	0.0000159
(UAV Stealth-50.0308)*(UAV speed-117.062)	-0.0000145
(Inf _3_ Pk pt1 st1-15.5077)*(ADA_1_ Pk st4-755.015)	0.0000043
(ADA_1_ sns rng st4-40.5077)*(ADA_1_ Pk st4-755.015)	-0.0000038
(UAV Stealth-50.0308)*(ADA_1_ Pk st4-755.015)	0.0000017
(UAV speed-117.062)*(ADA_1_ Pk st4-755.015)	0.0000011



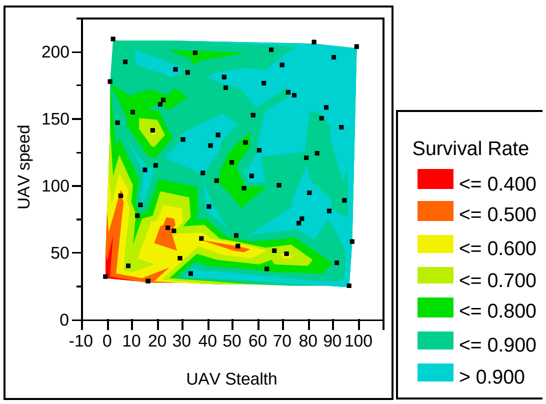
Residual by Predicted Plot

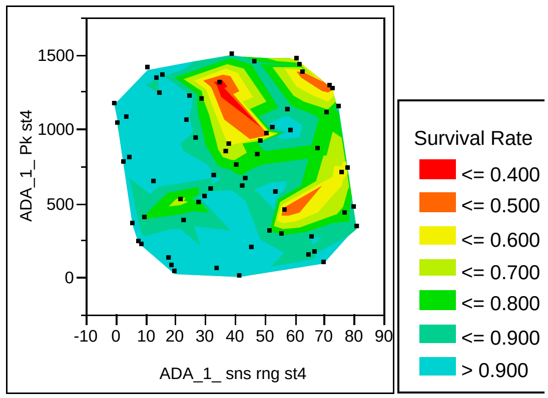


Residual by Row Plot



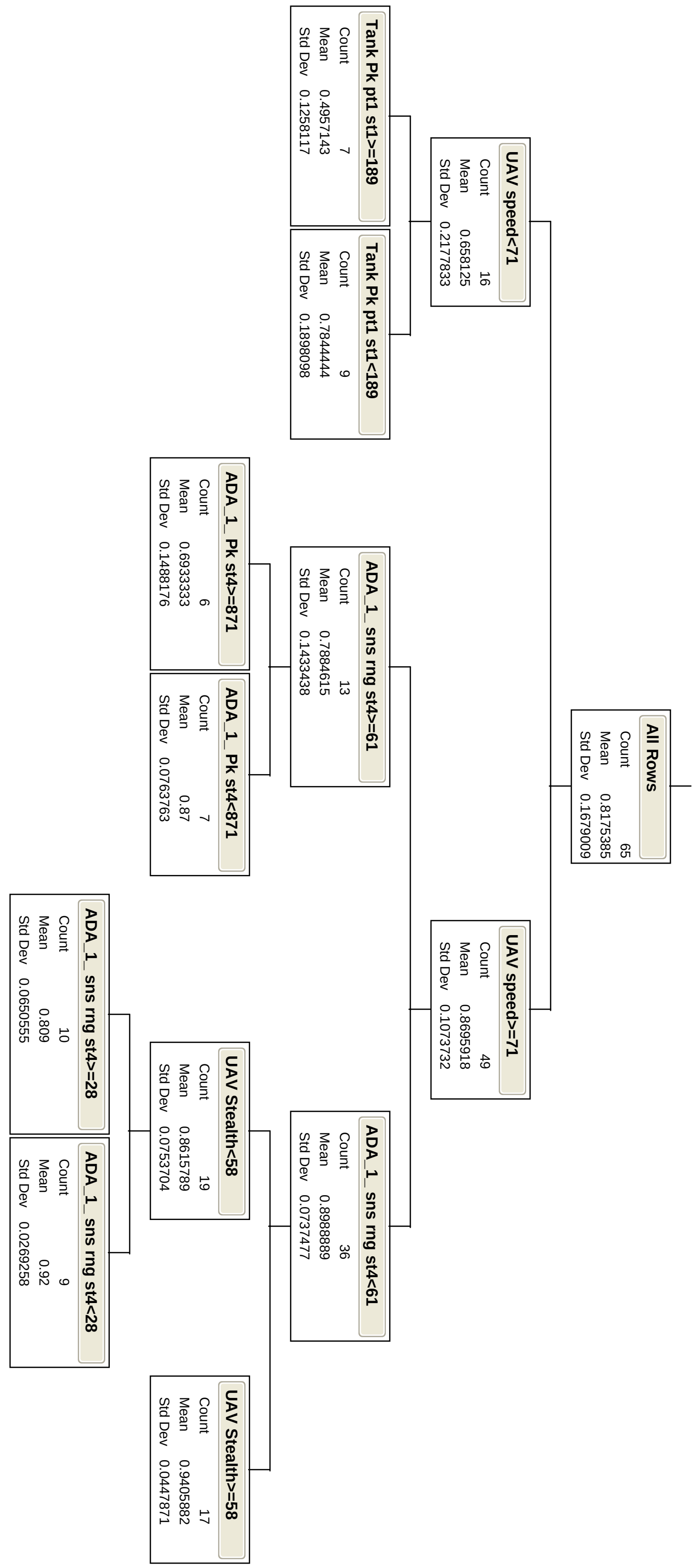
Contour Plots for Survival Rate





Partition for Survival Rate

RSquare	N	Imputes
0.665	65	0



Nominal Logistic Fit for Blue survive

Whole Model Test

Model	-LogLikelihood	DF	ChiSquare	Prob>ChiSq
Difference	558.4769	29	1116.954	<.0001
Full	2529.7093			
Reduced	3088.1863			

RSquare (U)	0.1808
Observations (or Sum Wgts)	6500

Converged by Objective

Lack Of Fit

Source	DF	-LogLikelihood	ChiSquare
Lack Of Fit	35	15.3350	30.6701
Saturated	64	2514.3743	Prob>ChiSq
Fitted	29	2529.7093	0.6772

Parameter Estimates

Term	Estimate	Std Error	ChiSquare	Prob>ChiSq
Intercept	-1.6467318	0.2742625	36.05	<.0001
UAV Stealth	-0.0243508	0.001787	185.69	<.0001
UAV enemy	-0.0024865	0.0013547	3.37	0.0664
UAV nxtwypt	0.00097437	0.0016982	0.33	0.5661
UAV sns rng	-0.0076712	0.0029212	6.90	0.0086
UAV speed	-0.0082992	0.0008348	98.84	<.0001
Tank Pk pt1 st1	0.00165706	0.0005092	10.59	0.0011
Inf _3_ Pk pt1 st1	0.02575042	0.0048764	27.88	<.0001
Inf 3 sns rng st1	0.01664261	0.0088672	3.52	0.0605
ADA_1_ sns rng st4	0.02342044	0.0017743	174.24	<.0001
ADA_1_ Pk st4	0.00108746	0.0001055	106.19	<.0001
(UAV Stealth-50.0308)*(UAV speed-117.062)	0.00003855	0.0000268	2.08	0.1496
(UAV Stealth-50.0308)*(ADA_1_ Pk st4-755.015)	0.00000292	0.0000049	0.35	0.5542
(UAV enemy-50.0308)*(UAV nxtwypt-55.0154)	0.00014924	0.0000594	6.32	0.0119
(UAV enemy-50.0308)*(Tank Pk pt1 st1-152.508)	-0.0000454	0.0000225	4.06	0.0438
(UAV enemy-50.0308)*(Inf _3_ Pk pt1 st1-15.5077)	0.00050008	0.0001685	8.81	0.0030
(UAV enemy-50.0308)*(ADA_1_ Pk st4-755.015)	0.00001575	0.0000035	20.11	<.0001
(UAV nxtwypt-55.0154)*(UAV sns rng-26.5077)	0.00015698	0.0001705	0.85	0.3572
(UAV nxtwypt-55.0154)*(UAV speed-117.062)	-0.0000329	0.0000467	0.49	0.4821
(UAV nxtwypt-55.0154)*(Tank Pk pt1 st1-152.508)	0.00015747	0.0000243	41.92	<.0001
(UAV nxtwypt-55.0154)*(ADA_1_ Pk st4-755.015)	-0.0000172	0.0000036	22.67	<.0001
(UAV sns rng-26.5077)*(UAV speed-117.062)	-0.0000848	0.0000601	1.99	0.1581
(UAV speed-117.062)*(ADA_1_ Pk st4-755.015)	-0.0000062	0.0000028	4.85	0.0277
(Tank Pk pt1 st1-152.508)*(Inf _3_ Pk pt1 st1-15.5077)	0.00044172	0.0000683	41.87	<.0001
(Inf _3_ Pk pt1 st1-15.5077)*(Inf 3 sns rng st1-9.01538)	0.00366762	0.0011189	10.74	0.0010
(Inf _3_ Pk pt1 st1-15.5077)*(ADA_1_ Pk st4-755.015)	-0.0000376	0.0000126	8.90	0.0028
(UAV Stealth-50.0308)*(UAV speed-117.062)*(ADA_1_ Pk st4-755.015)	3.15602e-7	1.0799e-7	8.54	0.0035
(UAV enemy-50.0308)*(UAV nxtwypt-55.0154)*(ADA_1_ Pk st4-755.015)	-6.6463e-7	1.1844e-7	31.49	<.0001
(UAV nxtwypt-55.0154)*(UAV sns rng-26.5077)*(UAV speed-117.062)	-0.0000111	0.0000045	6.12	0.0133
(UAV Stealth-50.0308)*(UAV Stealth-50.0308)	-0.0004557	0.0000694	43.17	<.0001

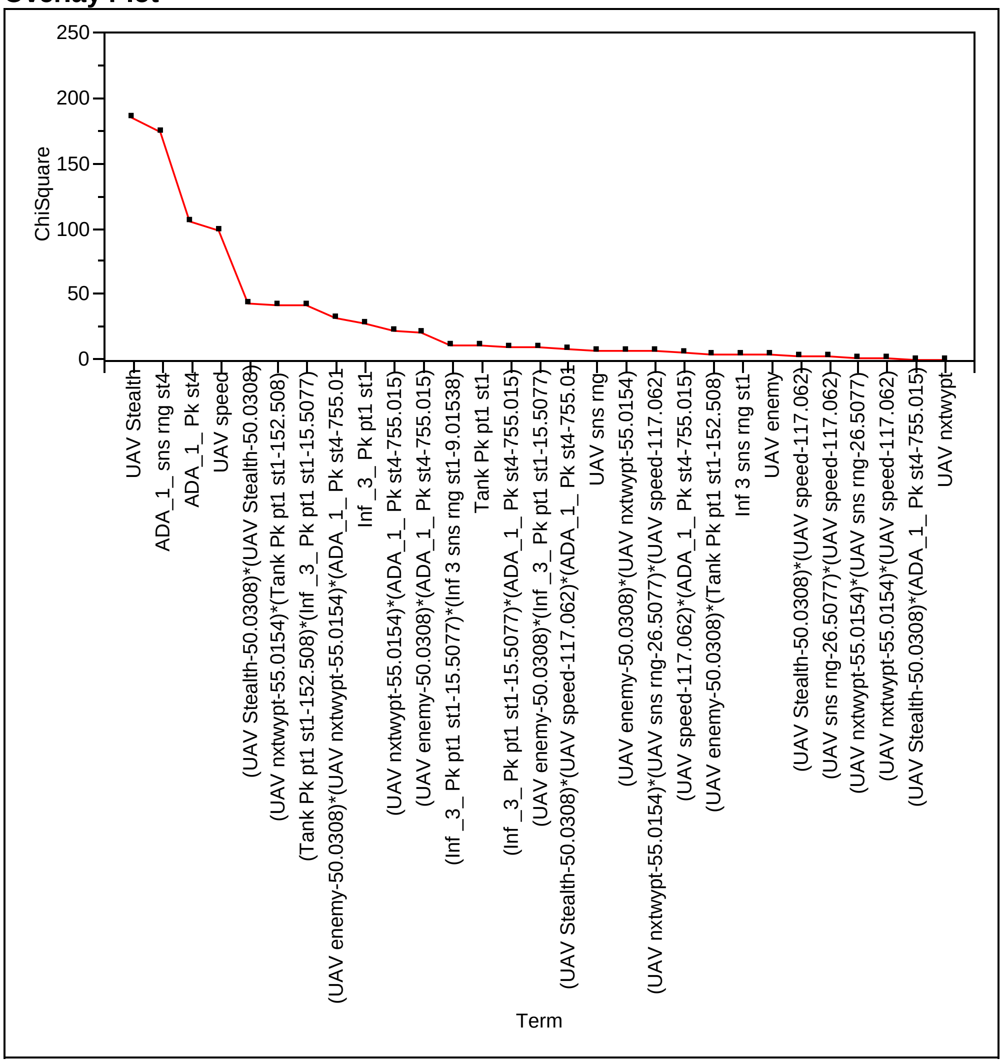
For log odds of 0/1

Effect Wald Tests

Source	Nparm	DF	Wald ChiSquare	Prob>ChiSq	
UAV Stealth	1	1	185.686792	0.0000	
UAV enemy	1	1	3.36861272	0.0664	
UAV nxtwypt	1	1	0.32920077	0.5661	
UAV sns rng	1	1	6.89627335	0.0086	
UAV speed	1	1	98.8364989	0.0000	
Tank Pk pt1 st1	1	1	10.5916254	0.0011	
Inf _3_ Pk pt1 st1	1	1	27.8844906	0.0000	
Inf 3 sns rng st1	1	1	3.52268587	0.0605	
ADA_1_ sns rng st4	1	1	174.243817	0.0000	
ADA_1_ Pk st4	1	1	106.192713	0.0000	
UAV Stealth*UAV speed	1	1	2.07630311	0.1496	

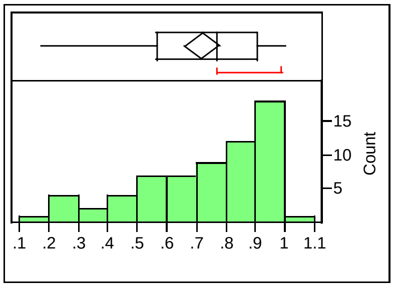
Source	Nparm	DF	Wald ChiSquare	Prob>ChiSq	
UAV Stealth*ADA_1_ Pk st4	1	1	0.34976801	0.5542	
UAV enemy*UAV nxtwypt	1	1	6.321344	0.0119	
UAV enemy*Tank Pk pt1 st1	1	1	4.06343015	0.0438	
UAV enemy*Inf _3_ Pk pt1 st1	1	1	8.80532582	0.0030	
UAV enemy*ADA_1_ Pk st4	1	1	20.113222	0.0000	
UAV nxtwypt*UAV sns rng	1	1	0.84760811	0.3572	
UAV nxtwypt*UAV speed	1	1	0.49405035	0.4821	
UAV nxtwypt*Tank Pk pt1 st1	1	1	41.9240579	0.0000	
UAV nxtwypt*ADA_1_ Pk st4	1	1	22.6743766	0.0000	
UAV sns rng*UAV speed	1	1	1.99266544	0.1581	
UAV speed*ADA_1_ Pk st4	1	1	4.84812225	0.0277	
Tank Pk pt1 st1*Inf _3_ Pk pt1 st1	1	1	41.8652579	0.0000	
Inf _3_ Pk pt1 st1*Inf 3 sns rng st1	1	1	10.744187	0.0010	
Inf _3_ Pk pt1 st1*ADA_1_ Pk st4	1	1	8.9043653	0.0028	
UAV Stealth*UAV speed*ADA_1_ Pk st4	1	0	0	0.0000	LostDFs
UAV enemy*UAV nxtwypt*ADA_1_ Pk st4	1	0	0	0.0000	LostDFs
UAV nxtwypt*UAV sns rng*UAV speed	1	1	6.12358547	0.0133	
UAV Stealth*UAV Stealth	1	1	43.1702811	0.0000	

Overlay Plot



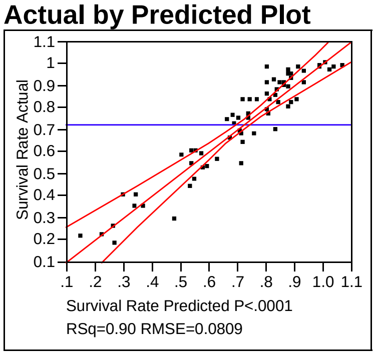
7. ALTERNATE TACTICAL LAYOUT 2

Distributions
Survival Rate



Moments	
Mean	0.7213846
Std Dev	0.2270523
Std Err Mean	0.0281624
upper 95% Mean	0.7776454
lower 95% Mean	0.6651238
N	65

Response Survival Rate
Actual by Predicted Plot



Summary of Fit

RSquare	0.902738
RSquare Adj	0.872964
Root Mean Square Error	0.080926
Mean of Response	0.721385
Observations (or Sum Wgts)	65

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	15	2.9784713	0.198565	30.3196
Error	49	0.3209041	0.006549	Prob > F
C. Total	64	3.2993754		<.0001

Parameter Estimates

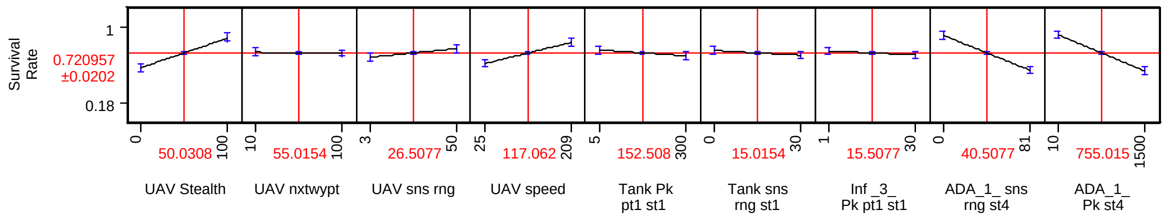
Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.8373473	0.056799	14.74	<.0001
UAV Stealth	0.0031472	0.000343	9.19	<.0001
UAV nxtwypt	-0.000168	0.00038	-0.44	0.6597
UAV sns rng	0.0019111	0.000727	2.63	0.0115
UAV speed	0.0012212	0.000186	6.56	<.0001
Tank Pk pt1 st1	-0.000209	0.000116	-1.80	0.0784
Tank sns rng st1	-0.001655	0.001137	-1.46	0.1518
Inf _3_ Pk pt1 st1	-0.001396	0.001179	-1.18	0.2419
ADA_1_ sns rng st4	-0.00457	0.000423	-10.80	<.0001
ADA_1_ Pk st4	-0.000258	0.000023	-11.22	<.0001
(UAV Stealth-50.0308)*(UAV speed-117.062)	-0.000017	0.000006	-2.94	0.0050
(UAV Stealth-50.0308)*(ADA_1_ sns rng st4-40.5077)	0.0000543	0.00002	2.77	0.0079
(UAV nxtwypt-55.0154)*(UAV sns rng-26.5077)	0.0000949	0.000029	3.29	0.0019
(UAV sns rng-26.5077)*(Tank sns rng st1-15.0154)	-0.000221	0.000084	-2.64	0.0112
(Tank Pk pt1 st1-152.508)*(Inf _3_ Pk pt1 st1-15.5077)	-0.000059	0.000017	-3.41	0.0013
(ADA_1_ sns rng st4-40.5077)*(ADA_1_ Pk st4-755.015)	-0.000005	0.000001	-5.18	<.0001

Effect Tests Altenate Tactical 2

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
UAV Stealth	1	1	0.55252711	84.3674	<.0001
UAV nxtwypt	1	1	0.00128528	0.1963	0.6597
UAV sns rng	1	1	0.04519704	6.9013	0.0115
UAV speed	1	1	0.28181358	43.0311	<.0001
Tank Pk pt1 st1	1	1	0.02116546	3.2318	0.0784
Tank sns rng st1	1	1	0.01388440	2.1201	0.1518
Inf _3_ Pk pt1 st1	1	1	0.00918893	1.4031	0.2419
ADA_1_ sns rng st4	1	1	0.76418946	116.6868	<.0001
ADA_1_ Pk st4	1	1	0.82482997	125.9463	<.0001
UAV Stealth*UAV speed	1	1	0.05658040	8.6395	0.0050
UAV Stealth*ADA_1_ sns rng st4	1	1	0.05032273	7.6840	0.0079
UAV nxtwypt*UAV sns rng	1	1	0.07072154	10.7987	0.0019
UAV sns rng*Tank sns rng st1	1	1	0.04550309	6.9480	0.0112
Tank Pk pt1 st1*Inf _3_ Pk pt1 st1	1	1	0.07630447	11.6512	0.0013
ADA_1_ sns rng st4*ADA_1_ Pk st4	1	1	0.17555260	26.8058	<.0001

Scaled Estimates

Prediction Profiler

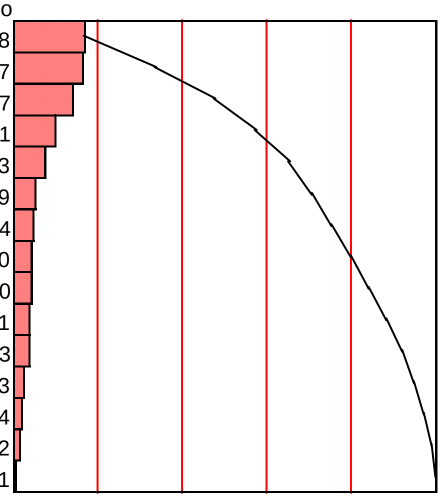


Effect Screening

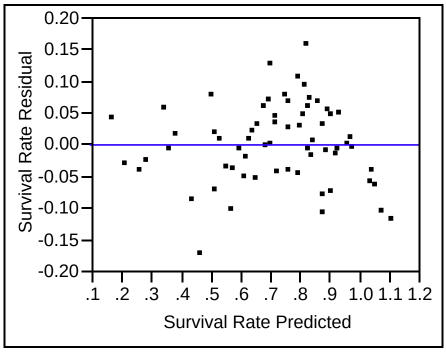
	Lenth PSE
t-Test Scale	4.8894756
Coded Scale	0.0490789

Pareto Plot of Estimates

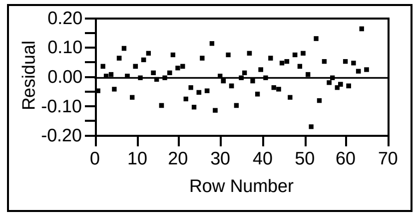
Term	t Ratio
ADA_1_ Pk st4	-11.22258
ADA_1_ sns rng st4	-10.80217
UAV Stealth	9.18517
UAV speed	6.55981
(ADA_1_ sns rng st4-40.5077)*(ADA_1_ Pk st4-755.015)	-5.17743
(Tank Pk pt1 st1-152.508)*(Inf _3_ Pk pt1 st1-15.5077)	-3.41339
(UAV nxtwypt-55.0154)*(UAV sns rng-26.5077)	3.28614
(UAV Stealth-50.0308)*(UAV speed-117.062)	-2.93930
(UAV Stealth-50.0308)*(ADA_1_ sns rng st4-40.5077)	2.77200
(UAV sns rng-26.5077)*(Tank sns rng st1-15.0154)	-2.63591
UAV sns rng	2.62703
Tank Pk pt1 st1	-1.79773
Tank sns rng st1	-1.45604
Inf _3_ Pk pt1 st1	-1.18452
UAV nxtwypt	-0.44301



Residual by Predicted Plot

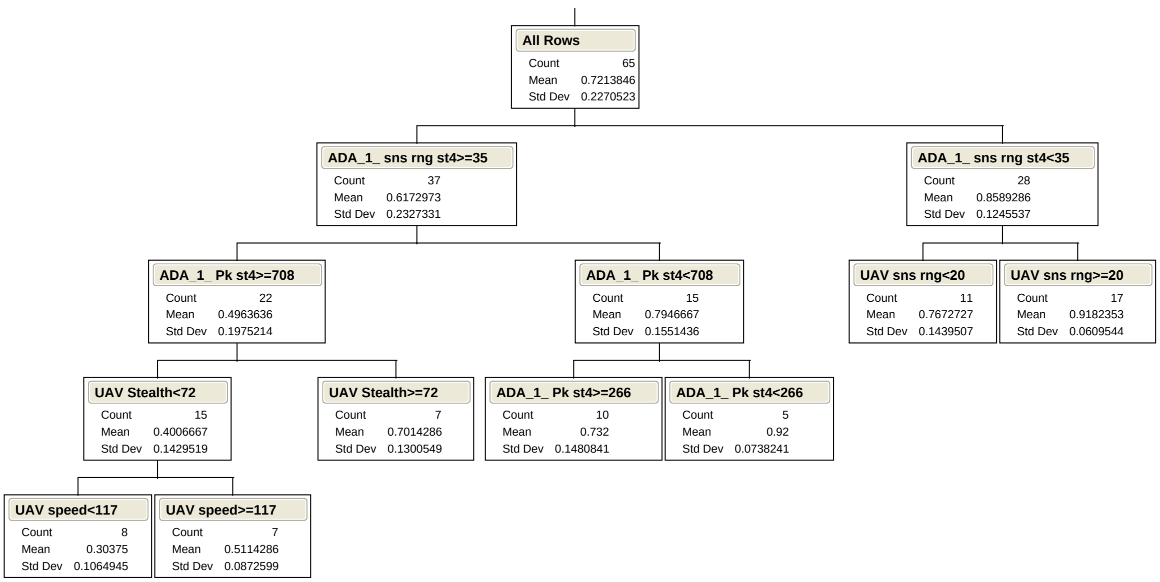


Residual by Row Plot



Partition for Survival Rate

RSquare	N	Imputes
0.784	65	0



Nominal Logistic Fit for Blue survive
Whole Model Test

Model	-LogLikelihood	DF	ChiSquare	Prob>ChiSq
Difference	858.1726	34	1716.345	0.0000
Full	2987.4928			
Reduced	3845.6655			

RSquare (U)	0.2232
Observations (or Sum Wgts)	6500

Converged by Objective

Lack Of Fit

Source	DF	-LogLikelihood	ChiSquare
Lack Of Fit	30	13.4163	26.83264
Saturated	64	2974.0765	Prob>ChiSq
Fitted	34	2987.4928	0.6320

Parameter Estimates

Term	Estimate	Std Error	ChiSquare	Prob>ChiSq
Intercept	-1.4335962	0.2702699	28.14	<.0001
UAV Stealth	-0.0235889	0.0013788	292.68	<.0001
UAV enemy	-0.0000618	0.0012944	0.00	0.9619
UAV nxtwypt	0.00507009	0.0015117	11.25	0.0008
UAV sns rng	-0.011416	0.0028042	16.57	<.0001
UAV speed	-0.0079001	0.0007182	121.00	<.0001
Tank Pk pt1 st1	0.00235272	0.0004653	25.57	<.0001
Tank sns rng st1	0.00257043	0.0041893	0.38	0.5395
Inf _3_ Pk pt1 st1	-0.0020315	0.0047281	0.18	0.6674
Inf 3 sns rng st1	-0.0028584	0.0072413	0.16	0.6930
ADA_1_ sns rng st4	0.03396935	0.0017508	376.46	<.0001
ADA_1_ Pk st4	0.00192236	0.0000936	421.70	<.0001
(UAV Stealth-50.0308)*(UAV enemy-50.0308)	0.00027611	0.0000955	8.37	0.0038
(UAV Stealth-50.0308)*(UAV nxtwypt-55.0154)	-0.0001855	0.0000558	11.05	0.0009
(UAV Stealth-50.0308)*(ADA_1_ sns rng st4-40.5077)	0.00033599	0.0000855	15.45	<.0001
(UAV enemy-50.0308)*(UAV nxtwypt-55.0154)	0.00007962	0.0000638	1.56	0.2123
(UAV enemy-50.0308)*(ADA_1_ Pk st4-755.015)	-0.0000021	0.0000043	0.24	0.6212
(UAV nxtwypt-55.0154)*(ADA_1_ Pk st4-755.015)	0.00000761	0.0000041	3.50	0.0615
(UAV sns rng-26.5077)*(Tank sns rng st1-15.0154)	0.00463883	0.0003653	161.29	<.0001
(UAV sns rng-26.5077)*(Inf 3 sns rng st1-9.01538)	0.00075172	0.0006342	1.41	0.2359
(UAV sns rng-26.5077)*(ADA_1_ sns rng st4-40.5077)	0.0005925	0.0001571	14.22	0.0002
(UAV speed-117.062)*(Inf _3_ Pk pt1 st1-15.5077)	-0.0003718	0.0000984	14.28	0.0002
(UAV speed-117.062)*(ADA_1_ sns rng st4-40.5077)	0.00013591	0.0000411	10.92	0.0009
(Tank Pk pt1 st1-152.508)*(Tank sns rng st1-15.0154)	-0.0003208	0.0000588	29.74	<.0001
(Tank Pk pt1 st1-152.508)*(ADA_1_ sns rng st4-40.5077)	-0.0000764	0.0000382	3.99	0.0457
(Tank sns rng st1-15.0154)*(Inf 3 sns rng st1-9.01538)	-0.0107554	0.0013003	68.42	<.0001
(Tank sns rng st1-15.0154)*(ADA_1_ sns rng st4-40.5077)	0.00022545	0.0002866	0.62	0.4315
(Inf _3_ Pk pt1 st1-15.5077)*(ADA_1_ sns rng st4-40.5077)	0.00039544	0.000228	3.01	0.0828
(UAV enemy-50.0308)*(UAV nxtwypt-55.0154)*(ADA_1_ Pk st4-755.015)	-6.0869e-7	1.0578e-7	33.11	<.0001
(UAV sns rng-26.5077)*(Tank sns rng st1-15.0154)*(Inf 3 sns rng st1-9.01538)	-0.0002276	0.0000798	8.13	0.0044
(UAV speed-117.062)*(Inf _3_ Pk pt1 st1-15.5077)*(ADA_1_ sns rng st4-40.5077)	0.00001814	0.0000038	23.09	<.0001
(Tank Pk pt1 st1-152.508)*(Tank sns rng st1-15.0154)*(ADA_1_ sns rng st4-40.5077)	0.00001456	0.0000052	7.70	0.0055
(UAV nxtwypt-55.0154)*(UAV nxtwypt-55.0154)	-0.000608	0.0000763	63.51	<.0001
(UAV speed-117.062)*(UAV speed-117.062)	-0.0000569	0.0000203	7.85	0.0051
(Inf _3_ Pk pt1 st1-15.5077)*(Inf _3_ Pk pt1 st1-15.5077)	-0.0056358	0.0006781	69.07	<.0001

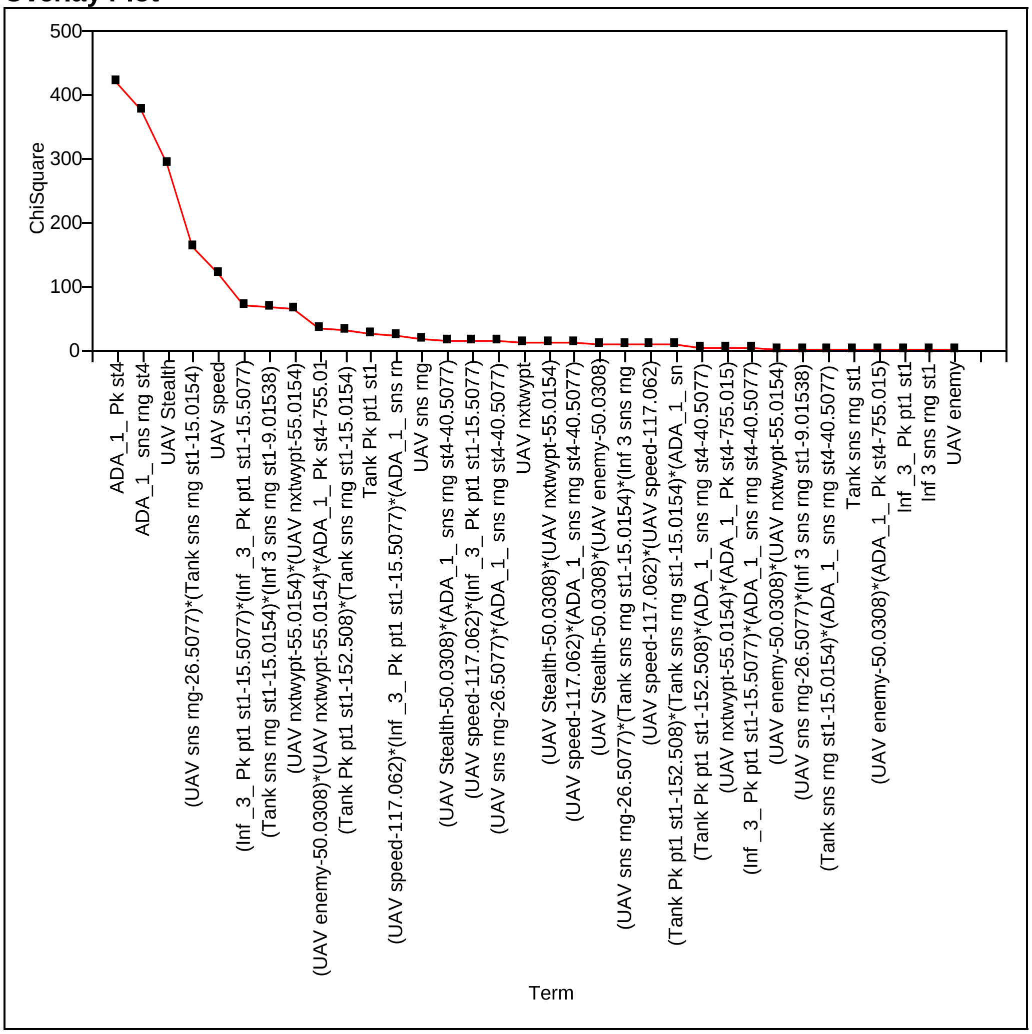
For log odds of 0/1

Effect Wald Tests

Source	Nparm	DF	Wald ChiSquare	Prob>ChiSq	
UAV Stealth	1	1	292.683009	0.0000	
UAV enemy	1	1	0.00228005	0.9619	
UAV nxtwypt	1	1	11.2491042	0.0008	
UAV sns rng	1	1	16.5736839	0.0000	
UAV speed	1	1	120.999798	0.0000	
Tank Pk pt1 st1	1	1	25.5695045	0.0000	
Tank sns rng st1	1	1	0.37646466	0.5395	
Inf _3_ Pk pt1 st1	1	1	0.18461516	0.6674	
Inf 3 sns rng st1	1	1	0.15581624	0.6930	
ADA_1_ sns rng st4	1	1	376.464315	0.0000	
ADA_1_ Pk st4	1	1	421.697911	0.0000	
UAV Stealth*UAV enemy	1	1	8.36733073	0.0038	
UAV Stealth*UAV nxtwypt	1	1	11.0483715	0.0009	
UAV Stealth*ADA_1_ sns rng st4	1	1	15.4476694	0.0001	
UAV enemy*UAV nxtwypt	1	1	1.55552588	0.2123	
UAV enemy*ADA_1_ Pk st4	1	1	0.24420514	0.6212	
UAV nxtwypt*ADA_1_ Pk st4	1	1	3.49581136	0.0615	
UAV sns rng*Tank sns rng st1	1	1	161.291904	0.0000	
UAV sns rng*Inf 3 sns rng st1	1	1	1.40500673	0.2359	
UAV sns rng*ADA_1_ sns rng st4	1	1	14.2192949	0.0002	
UAV speed*Inf _3_ Pk pt1 st1	1	1	14.2756482	0.0002	
UAV speed*ADA_1_ sns rng st4	1	1	10.9245784	0.0009	

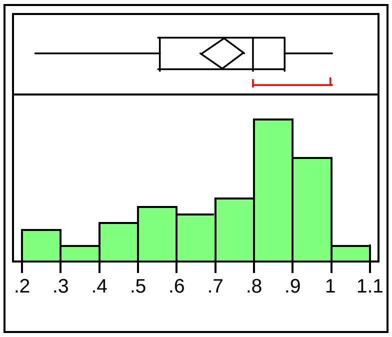
Source	Nparm	DF	Wald ChiSquare	Prob>ChiSq	
Tank Pk pt1 st1*Tank sns rng st1	1	1	29.7355805	0.0000	
Tank Pk pt1 st1*ADA_1_ sns rng st4	1	1	3.99357028	0.0457	
Tank sns rng st1*Inf 3 sns rng st1	1	1	68.4151961	0.0000	
Tank sns rng st1*ADA_1_ sns rng st4	1	1	0.61868325	0.4315	
Inf _3_ Pk pt1 st1*ADA_1_ sns rng st4	1	1	3.00913443	0.0828	
UAV enemy*UAV nxtwypt*ADA_1_ Pk st4	1	0	0	0.0000	LostDFs
UAV sns rng*Tank sns rng st1*Inf 3 sns rng st1	1	1	8.13130286	0.0044	
UAV speed*Inf _3_ Pk pt1 st1*ADA_1_ sns rng st4	1	1	23.0929833	0.0000	
Tank Pk pt1 st1*Tank sns rng st1*ADA_1_ sns rng st4	1	1	7.69771724	0.0055	
UAV nxtwypt*UAV nxtwypt	1	1	63.5112042	0.0000	
UAV speed*UAV speed	1	1	7.853367	0.0051	
Inf _3_ Pk pt1 st1*Inf _3_ Pk pt1 st1	1	1	69.0713549	0.0000	

Overlay Plot



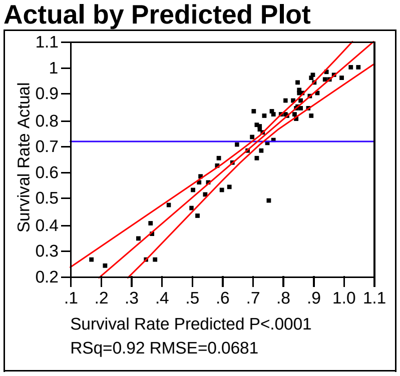
8. ALTERNATE TACTICAL LAYOUT 3

Distributions
Survival Rate



Moments	
Mean	0.7212308
Std Dev	0.2099219
Std Err Mean	0.0260376
upper 95% Mean	0.7732469
lower 95% Mean	0.6692147
N	65

Response Survival Rate
Actual by Predicted Plot



Summary of Fit

RSquare	0.917793
RSquare Adj	0.894775
Root Mean Square Error	0.068095
Mean of Response	0.721231
Observations (or Sum Wgts)	65

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	14	2.5884526	0.184889	39.8728
Error	50	0.2318489	0.004637	Prob > F
C. Total	64	2.8203015		<.0001

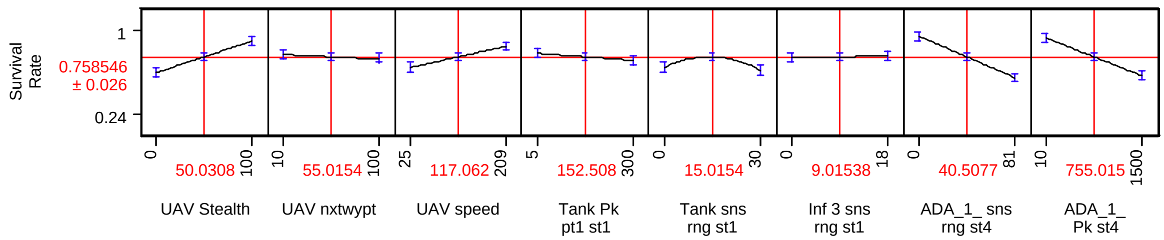
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.9181297	0.045574	20.15	<.0001
UAV Stealth	0.0028162	0.000288	9.77	<.0001
UAV nxtwypt	-0.00046	0.00032	-1.44	0.1563
UAV speed	0.0010326	0.000157	6.59	<.0001
Tank Pk pt1 st1	-0.000209	0.000098	-2.14	0.0376
Tank sns rng st1	-0.000905	0.000956	-0.95	0.3488
Inf 3 sns rng st1	0.0007739	0.001602	0.48	0.6312
ADA_1_ sns rng st4	-0.004581	0.000356	-12.87	<.0001
ADA_1_ Pk st4	-0.000228	0.000019	-11.78	<.0001
(UAV Stealth-50.0308)*(UAV speed-117.062)	-0.000026	0.000005	-5.17	<.0001
(UAV nxtwypt-55.0154)*(Tank Pk pt1 st1-152.508)	-0.000014	0.000005	-3.00	0.0042
(UAV speed-117.062)*(ADA_1_ sns rng st4-40.5077)	0.0000143	0.000007	2.10	0.0405
(Tank sns rng st1-15.0154)*(Inf 3 sns rng st1-9.01538)	0.001375	0.000234	5.87	<.0001
(ADA_1_ sns rng st4-40.5077)*(ADA_1_ Pk st4-755.015)	-0.000002	9.686e-7	-2.35	0.0227
(Tank sns rng st1-15.0154)*(Tank sns rng st1-15.0154)	-0.000467	0.000125	-3.73	0.0005

Effect Tests Alternate Tactical 3

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
UAV Stealth	1	1	0.44225821	95.3764	<.0001
UAV nxtwypt	1	1	0.00960578	2.0716	0.1563
UAV speed	1	1	0.20136899	43.4268	<.0001
Tank Pk pt1 st1	1	1	0.02116221	4.5638	0.0376
Tank sns rng st1	1	1	0.00414842	0.8946	0.3488
Inf 3 sns rng st1	1	1	0.00108169	0.2333	0.6312
ADA_1_ sns rng st4	1	1	0.76795445	165.6153	<.0001
ADA_1_ Pk st4	1	1	0.64346863	138.7690	<.0001
UAV Stealth*UAV speed	1	1	0.12398851	26.7391	<.0001
UAV nxtwypt*Tank Pk pt1 st1	1	1	0.04163560	8.9790	0.0042
UAV speed*ADA_1_ sns rng st4	1	1	0.02052082	4.4255	0.0405
Tank sns rng st1*Inf 3 sns rng st1	1	1	0.15961606	34.4224	<.0001
ADA_1_ sns rng st4*ADA_1_ Pk st4	1	1	0.02563854	5.5291	0.0227
Tank sns rng st1*Tank sns rng st1	1	1	0.06434829	13.8772	0.0005

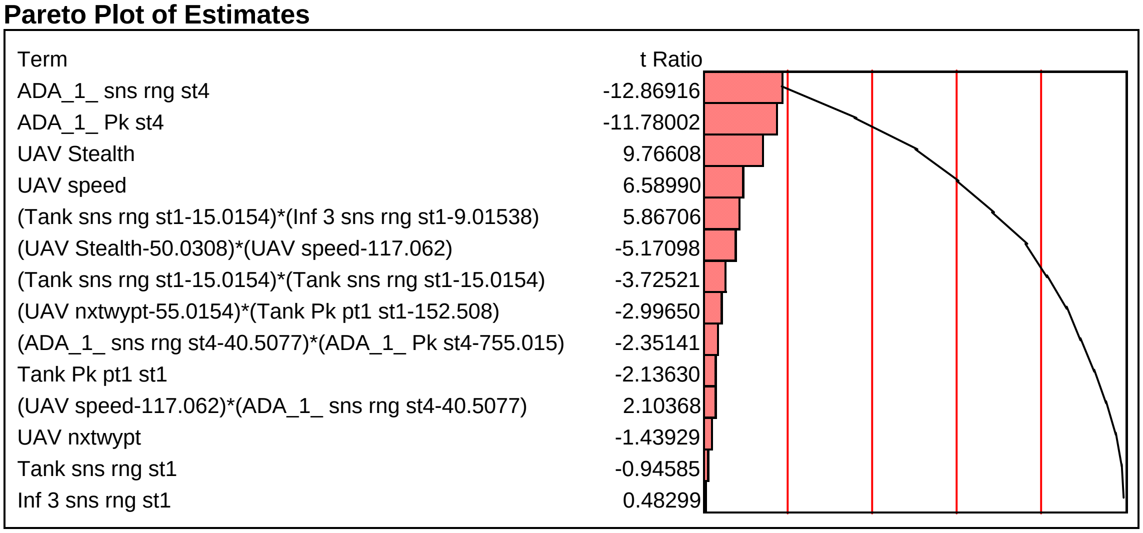
Prediction Profiler



Effect Screening

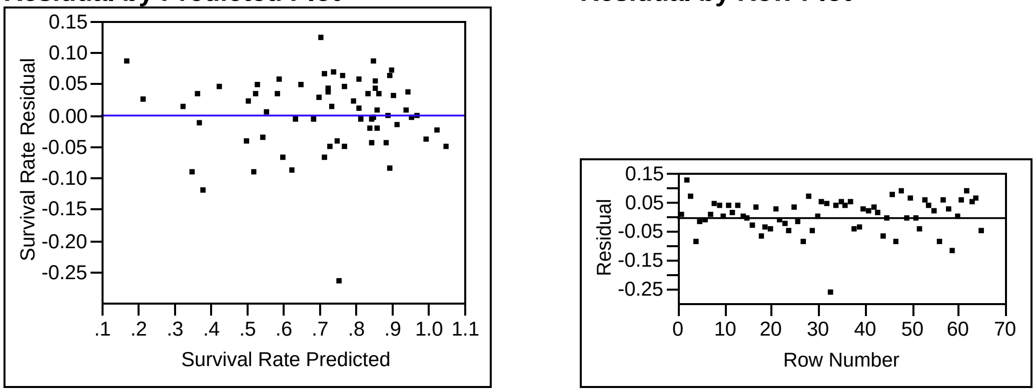
	Lenth PSE
t-Test Scale	6.3788604
Coded Scale	0.0538771

Pareto Plot of Estimates

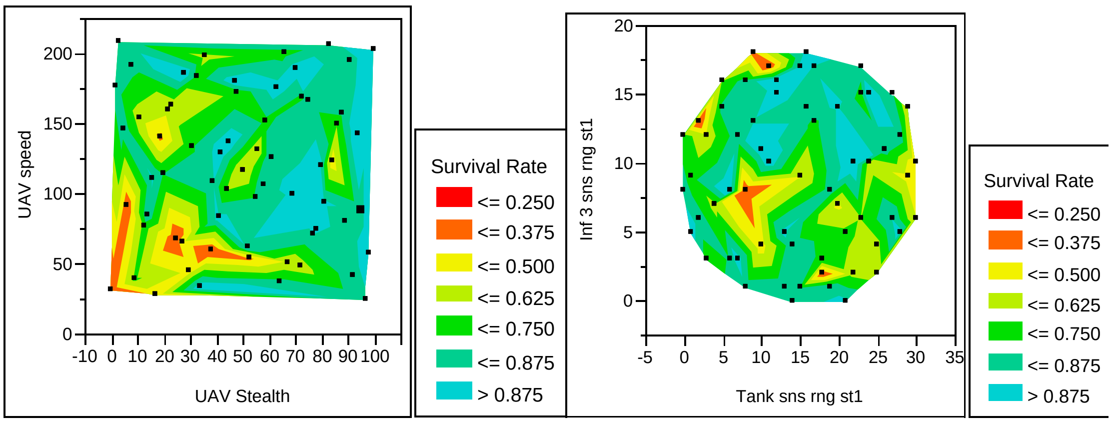


Residual by Predicted Plot

Residual by Row Plot

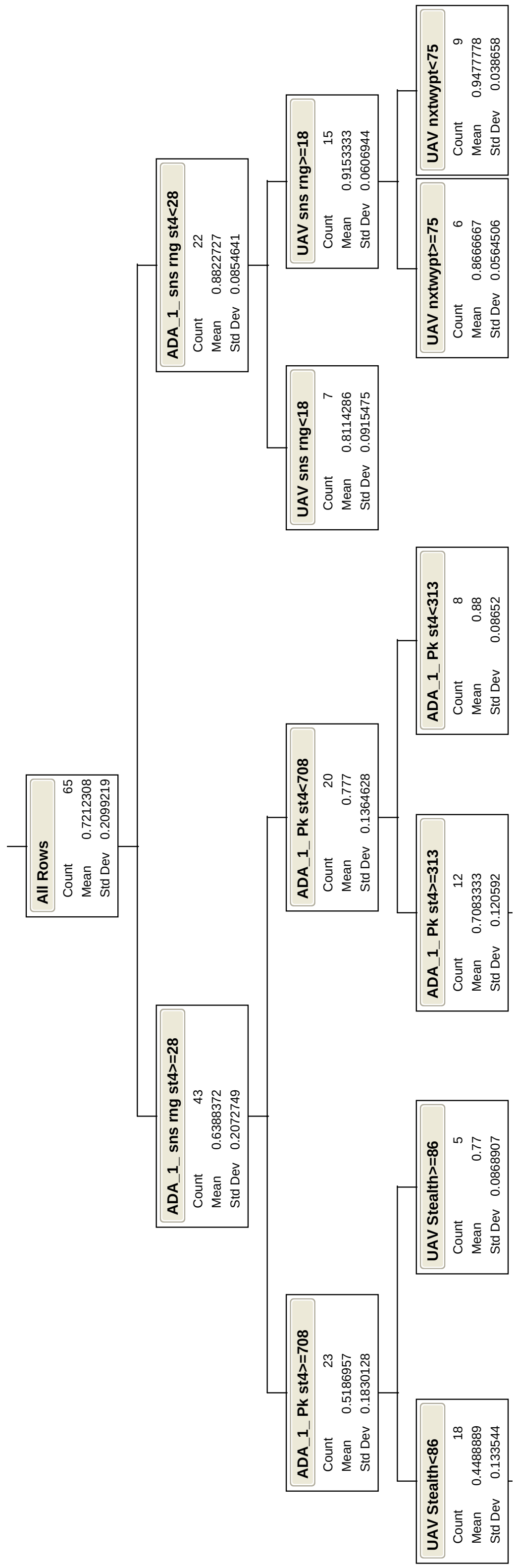


Contour Plots for Survival Rate



Partition for Survival Rate

RSquare	N	Imputes
0.858	65	0



Nominal Logistic Fit for Blue survive

Whole Model Test

Model	-LogLikelihood	DF	ChiSquare	Prob>ChiSq
Difference	735.9636	49	1471.927	<.0001
Full	3110.6528			
Reduced	3846.6164			

RSquare (U)	0.1913
Observations (or Sum Wgts)	6500

Converged by Objective

Lack Of Fit

Source	DF	-LogLikelihood	ChiSquare
Lack Of Fit	15	1.7070	3.414047
Saturated	64	3108.9458	Prob>ChiSq
Fitted	49	3110.6528	0.9991

Parameter Estimates

Term	Estimate	Std Error	ChiSquare	Prob>ChiSq
Intercept	-0.8593241	0.3134997	7.51	0.0061
UAV Stealth	-0.0210898	0.0017499	145.25	<.0001
UAV enemy	0.00039727	0.001587	0.06	0.8023
UAV nxtwypt	-0.0032956	0.0026636	1.53	0.2160
UAV sns rng	-0.0034047	0.0027695	1.51	0.2189
UAV speed	-0.004818	0.0009015	28.56	<.0001
Tank Pk pt1 st1	-0.0005677	0.0007116	0.64	0.4250
Tank sns rng st1	0.01025608	0.0041713	6.05	0.0139
Inf _3_ Pk pt1 st1	0.01931612	0.0055836	11.97	0.0005
Inf 3 sns rng st1	-0.012008	0.01141	1.11	0.2926
ADA_1_ sns rng st4	0.02919661	0.001992	214.83	<.0001
ADA_1_ Pk st4	0.00172777	0.0001368	159.63	<.0001
(UAV Stealth-50.0308)*(UAV enemy-50.0308)	-0.0000135	0.0000977	0.02	0.8902
(UAV Stealth-50.0308)*(UAV nxtwypt-55.0154)	0.00002968	0.00006	0.24	0.6210
(UAV Stealth-50.0308)*(UAV speed-117.062)	0.00003313	0.0000322	1.06	0.3030
(UAV Stealth-50.0308)*(Inf _3_ Pk pt1 st1-15.5077)	-0.0009581	0.000231	17.20	<.0001
(UAV Stealth-50.0308)*(ADA_1_ sns rng st4-40.5077)	0.00012954	0.0002558	0.26	0.6126
(UAV Stealth-50.0308)*(ADA_1_ Pk st4-755.015)	0.00000489	0.0000039	1.56	0.2120
(UAV enemy-50.0308)*(UAV speed-117.062)	0.00012573	0.0000338	13.81	0.0002
(UAV enemy-50.0308)*(Tank Pk pt1 st1-152.508)	0.00006942	0.0000686	1.02	0.3114
(UAV enemy-50.0308)*(Tank sns rng st1-15.0154)	0.00102609	0.0002755	13.87	0.0002
(UAV enemy-50.0308)*(Inf _3_ Pk pt1 st1-15.5077)	-0.0001828	0.0002231	0.67	0.4125
(UAV enemy-50.0308)*(Inf 3 sns rng st1-9.01538)	0.00145812	0.0005401	7.29	0.0069
(UAV enemy-50.0308)*(ADA_1_ sns rng st4-40.5077)	0.00022558	0.000062	13.24	0.0003
(UAV nxtwypt-55.0154)*(UAV speed-117.062)	0.00006736	0.0000876	0.59	0.4417
(UAV nxtwypt-55.0154)*(ADA_1_ sns rng st4-40.5077)	-0.000063	0.0000834	0.57	0.4503
(UAV sns rng-26.5077)*(Inf _3_ Pk pt1 st1-15.5077)	-0.0018548	0.0011837	2.46	0.1171
(UAV speed-117.062)*(Tank sns rng st1-15.0154)	-0.0001537	0.0000931	2.73	0.0987
(UAV speed-117.062)*(ADA_1_ sns rng st4-40.5077)	-0.0000309	0.0000449	0.47	0.4912
(UAV speed-117.062)*(ADA_1_ Pk st4-755.015)	0.00000284	0.0000034	0.71	0.3987
(Tank Pk pt1 st1-152.508)*(Tank sns rng st1-15.0154)	0.00007022	0.0000654	1.15	0.2831
(Tank Pk pt1 st1-152.508)*(Inf _3_ Pk pt1 st1-15.5077)	0.00007506	0.000104	0.52	0.4704
(Tank Pk pt1 st1-152.508)*(Inf 3 sns rng st1-9.01538)	0.00048542	0.0001521	10.19	0.0014
(Tank sns rng st1-15.0154)*(Inf 3 sns rng st1-9.01538)	-0.0073026	0.0020886	12.22	0.0005
(Inf _3_ Pk pt1 st1-15.5077)*(Inf 3 sns rng st1-9.01538)	0.01085582	0.0029416	13.62	0.0002
(Inf _3_ Pk pt1 st1-15.5077)*(ADA_1_ sns rng st4-40.5077)	0.00039494	0.000223	3.14	0.0766
(ADA_1_ sns rng st4-40.5077)*(ADA_1_ Pk st4-755.015)	0.00001337	0.0000126	1.12	0.2903
(UAV Stealth-50.0308)*(UAV enemy-50.0308)*(ADA_1_ sns rng st4-40.5077)	-0.0000084	0.0000052	2.63	0.1047
(UAV Stealth-50.0308)*(UAV nxtwypt-55.0154)*(UAV speed-117.062)	-0.0000044	0.0000015	8.24	0.0041
(UAV Stealth-50.0308)*(UAV speed-117.062)*(ADA_1_ sns rng st4-40.5077)	-0.0000078	0.0000028	7.69	0.0055
(UAV Stealth-50.0308)*(UAV speed-117.062)*(ADA_1_ Pk st4-755.015)	1.95423e-7	9.3121e-8	4.40	0.0359
(UAV enemy-50.0308)*(UAV speed-117.062)*(ADA_1_ sns rng st4-40.5077)	0.00000286	9.1628e-7	9.71	0.0018
(UAV enemy-50.0308)*(Tank Pk pt1 st1-152.508)*(Tank sns rng st1-	0.00002504	0.0000069	13.00	0.0003

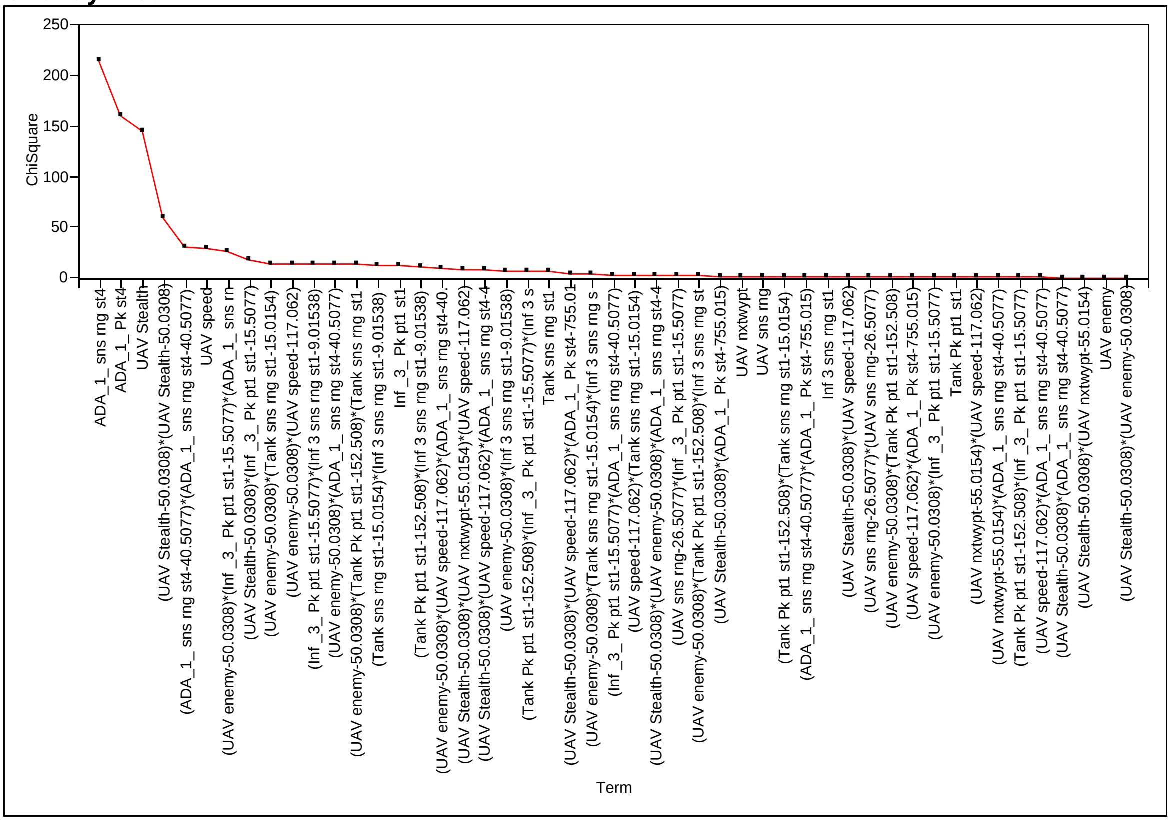
Term	Estimate	Std Error	ChiSquare	Prob>ChiSq
15.0154)				
(UAV enemy-50.0308)*(Tank Pk pt1 st1-152.508)*(Inf 3 sns rng st1-9.01538)	-0.0000078	0.000005	2.37	0.1238
(UAV enemy-50.0308)*(Tank sns rng st1-15.0154)*(Inf 3 sns rng st1-9.01538)	0.00017085	0.0000819	4.35	0.0370
(UAV enemy-50.0308)*(Inf _3_ Pk pt1 st1-15.5077)*(ADA_1_ sns rng st4-40.5077)	-0.0000399	0.0000077	26.60	<.0001
(Tank Pk pt1 st1-152.508)*(Inf _3_ Pk pt1 st1-15.5077)*(Inf 3 sns rng st1-9.01538)	0.00006422	0.000025	6.59	0.0103
(UAV Stealth-50.0308)*(UAV Stealth-50.0308)	-0.0007714	0.0000995	60.08	<.0001
(UAV sns rng-26.5077)*(UAV sns rng-26.5077)	-0.0004239	0.0004145	1.05	0.3066
(ADA_1_ sns rng st4-40.5077)*(ADA_1_ sns rng st4-40.5077)	-0.0010434	0.0001879	30.82	<.0001

For log odds of 0/1

Effect Wald Tests

Source	Nparm	DF	Wald ChiSquare	Prob>ChiSq	
UAV Stealth	1	1	145.253296	0.0000	
UAV enemy	1	1	0.06266692	0.8023	
UAV nxtwypt	1	1	1.53077581	0.2160	
UAV sns rng	1	1	1.51135183	0.2189	
UAV speed	1	1	28.5647168	0.0000	
Tank Pk pt1 st1	1	1	0.63644067	0.4250	
Tank sns rng st1	1	1	6.04522042	0.0139	
Inf _3_ Pk pt1 st1	1	1	11.9675323	0.0005	
Inf 3 sns rng st1	1	1	1.10755441	0.2926	
ADA_1_ sns rng st4	1	1	214.833058	0.0000	
ADA_1_ Pk st4	1	1	159.630196	0.0000	
UAV Stealth*UAV enemy	1	1	0.0190591	0.8902	
UAV Stealth*UAV nxtwypt	1	1	0.2445279	0.6210	
UAV Stealth*UAV speed	1	1	1.061038	0.3030	
UAV Stealth*Inf _3_ Pk pt1 st1	1	1	17.2003004	0.0000	
UAV Stealth*ADA_1_ sns rng st4	1	1	0.25646578	0.6126	
UAV Stealth*ADA_1_ Pk st4	1	1	1.55737994	0.2120	
UAV enemy*UAV speed	1	1	13.8068799	0.0002	
UAV enemy*Tank Pk pt1 st1	1	1	1.02493361	0.3114	
UAV enemy*Tank sns rng st1	1	1	13.870198	0.0002	
UAV enemy*Inf _3_ Pk pt1 st1	1	1	0.6715596	0.4125	
UAV enemy*Inf 3 sns rng st1	1	1	7.28860564	0.0069	
UAV enemy*ADA_1_ sns rng st4	1	1	13.2438643	0.0003	
UAV nxtwypt*UAV speed	1	1	0.59175657	0.4417	
UAV nxtwypt*ADA_1_ sns rng st4	1	1	0.56989545	0.4503	
UAV sns rng*Inf _3_ Pk pt1 st1	1	1	2.45558547	0.1171	
UAV speed*Tank sns rng st1	1	1	2.72605373	0.0987	
UAV speed*ADA_1_ sns rng st4	1	1	0.4738863	0.4912	
UAV speed*ADA_1_ Pk st4	1	1	0.71215161	0.3987	
Tank Pk pt1 st1*Tank sns rng st1	1	1	1.15227577	0.2831	
Tank Pk pt1 st1*Inf _3_ Pk pt1 st1	1	1	0.52095238	0.4704	
Tank Pk pt1 st1*Inf 3 sns rng st1	1	1	10.1853671	0.0014	
Tank sns rng st1*Inf 3 sns rng st1	1	1	12.2247978	0.0005	
Inf _3_ Pk pt1 st1*Inf 3 sns rng st1	1	1	13.6193875	0.0002	
Inf _3_ Pk pt1 st1*ADA_1_ sns rng st4	1	1	3.13602326	0.0766	
ADA_1_ sns rng st4*ADA_1_ Pk st4	1	1	1.11825882	0.2903	
UAV Stealth*UAV enemy*ADA_1_ sns rng st4	1	1	2.63226709	0.1047	
UAV Stealth*UAV nxtwypt*UAV speed	1	1	8.23794239	0.0041	
UAV Stealth*UAV speed*ADA_1_ sns rng st4	1	1	7.69457239	0.0055	
UAV Stealth*UAV speed*ADA_1_ Pk st4	1	0	0	0.0000	LostDFs
UAV enemy*UAV speed*ADA_1_ sns rng st4	1	0	0	0.0000	LostDFs
UAV enemy*Tank Pk pt1 st1*Tank sns rng st1	1	1	13.0009509	0.0003	
UAV enemy*Tank Pk pt1 st1*Inf 3 sns rng st1	1	1	2.36873765	0.1238	
UAV enemy*Tank sns rng st1*Inf 3 sns rng st1	1	1	4.34899028	0.0370	
UAV enemy*Inf _3_ Pk pt1 st1*ADA_1_ sns rng st4	1	1	26.6028829	0.0000	
Tank Pk pt1 st1*Inf _3_ Pk pt1 st1*Inf 3 sns rng st1	1	1	6.58935387	0.0103	
UAV Stealth*UAV Stealth	1	1	60.0818981	0.0000	
UAV sns rng*UAV sns rng	1	1	1.04540536	0.3066	
ADA_1_ sns rng st4*ADA_1_ sns rng st4	1	1	30.8174709	0.0000	

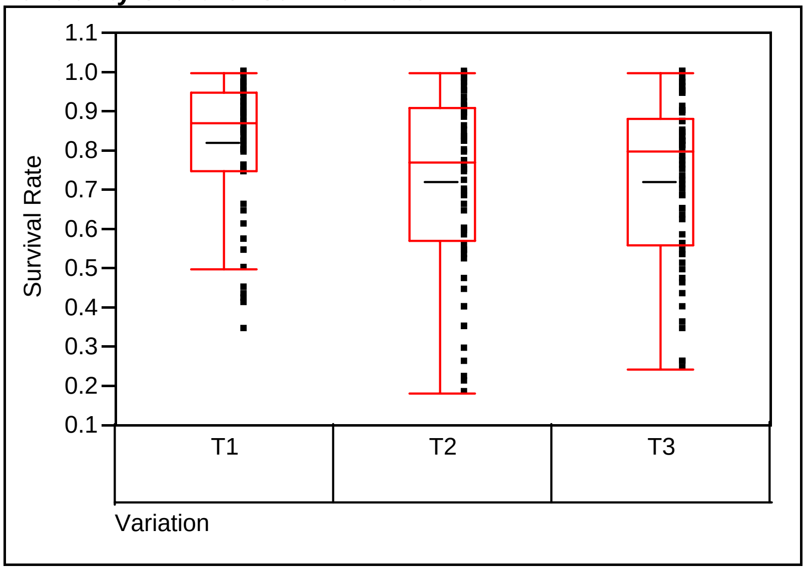
Overlay Plot

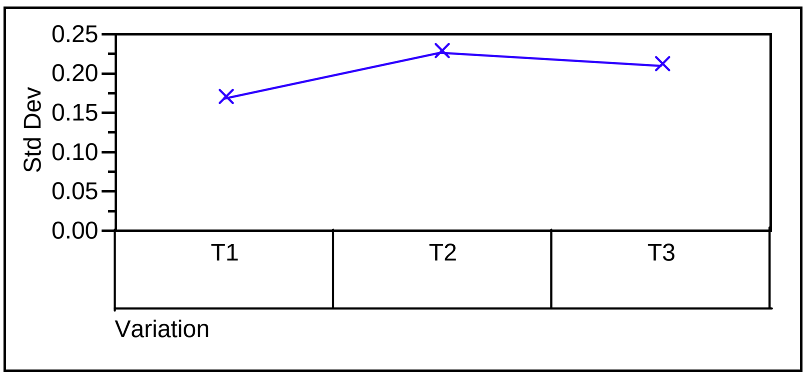


9. TACTICAL SUMMARY

Variability Gage

Variability Chart for Survival Rate





Analysis of Variance

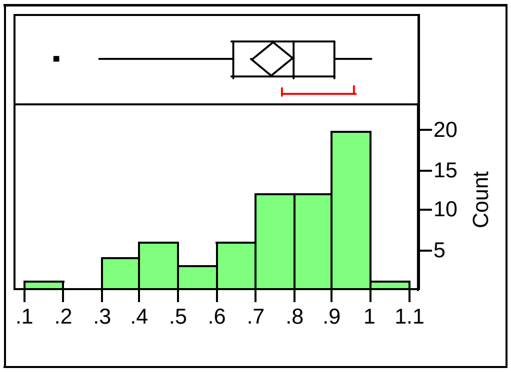
Source	DF	SS	Mean Square	F Ratio	Prob > F
Variation	2	0.401283	0.20064	4.86165	0.0087
Within	192	7.923883	0.04127		
Total	194	8.325166	0.04291		

Variance Components

Component	Var Component	% of Total	Plot%	Sqrt(Var Comp)
Variation	0.00245187	5.6		0.04952
Within	0.04127022	94.4		0.20315
Total	0.04372209	100.0		0.20910

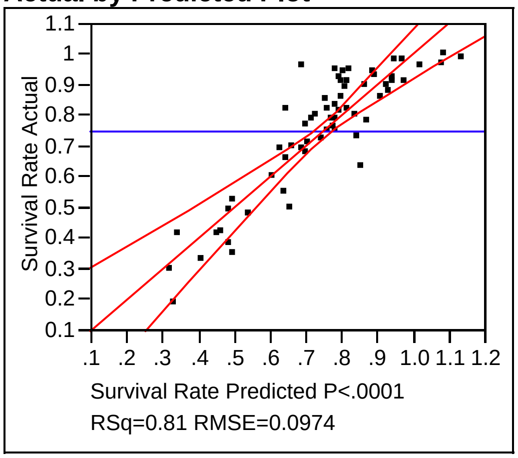
10. 2 X THREAT LEVEL SPREAD

Distributions
Survival Rate



Moments	
Mean	0.7473846
Std Dev	0.2032876
Std Err Mean	0.0252147
upper 95% Mean	0.7977568
lower 95% Mean	0.6970124
N	65

Response Survival Rate
Actual by Predicted Plot



Summary of Fit

RSquare	0.809803
RSquare Adj	0.770328
Root Mean Square Error	0.097424
Mean of Response	0.747385
Observations (or Sum Wgts)	65

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	2.1418114	0.194710	20.5144
Error	53	0.5030440	0.009491	Prob > F
C. Total	64	2.6448554		<.0001

Parameter Estimates

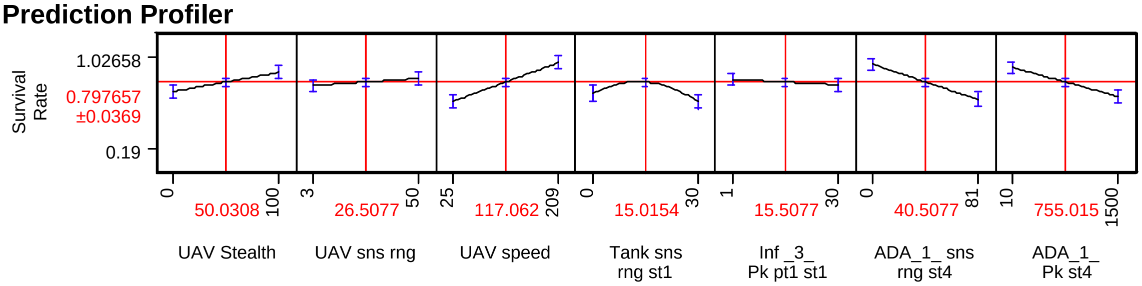
Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.8124961	0.061359	13.24	<.0001
UAV Stealth	0.001704	0.000412	4.13	0.0001
UAV sns rng	0.0013406	0.000876	1.53	0.1318
UAV speed	0.001886	0.000224	8.42	<.0001
Tank sns rng st1	-0.002535	0.001368	-1.85	0.0695
Inf _3_ Pk pt1 st1	-0.001697	0.001419	-1.20	0.2369
ADA_1_ sns rng st4	-0.003944	0.000509	-7.74	<.0001

Term	Estimate	Std Error	t Ratio	Prob>|t|
ADA_1_ Pk st4	-0.000175	0.000028	-6.33	<.0001
(UAV sns rng-26.5077)*(UAV speed-117.062)	-0.000039	0.000017	-2.30	0.0256
(Tank sns rng st1-15.0154)*(Inf _3_ Pk pt1 st1-15.5077)	-0.000482	0.000159	-3.04	0.0037
(Tank sns rng st1-15.0154)*(ADA_1_ Pk st4-755.015)	0.0000088	0.000004	2.47	0.0167
(Tank sns rng st1-15.0154)*(Tank sns rng st1-15.0154)	-0.000636	0.000178	-3.58	0.0008

Effect Tests 2X Threat, Spread

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
UAV Stealth	1	1	0.16197314	17.0653	0.0001
UAV sns rng	1	1	0.02224133	2.3433	0.1318
UAV speed	1	1	0.67217871	70.8198	<.0001
Tank sns rng st1	1	1	0.03258508	3.4331	0.0695
Inf _3_ Pk pt1 st1	1	1	0.01358445	1.4312	0.2369
ADA_1_ sns rng st4	1	1	0.56904213	59.9535	<.0001
ADA_1_ Pk st4	1	1	0.38053674	40.0928	<.0001
UAV sns rng*UAV speed	1	1	0.05006941	5.2752	0.0256
Tank sns rng st1*Inf _3_ Pk pt1 st1	1	1	0.08767898	9.2377	0.0037
Tank sns rng st1*ADA_1_ Pk st4	1	1	0.05792950	6.1034	0.0167
Tank sns rng st1*Tank sns rng st1	1	1	0.12134872	12.7851	0.0008

Prediction Profiler

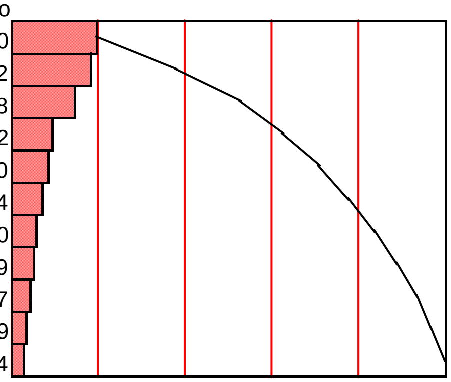


Effect Screening

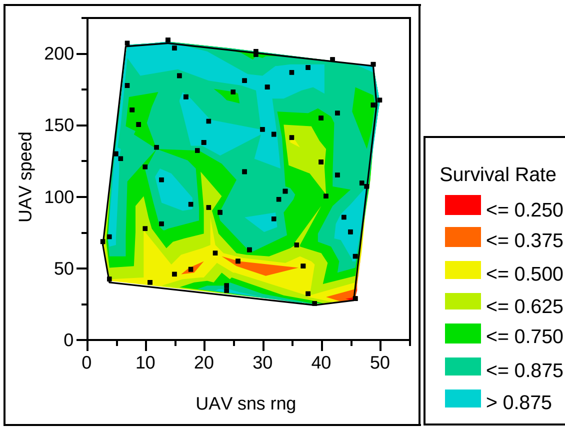
	Lenth PSE
t-Test Scale	5.1965886
Coded Scale	0.0627952

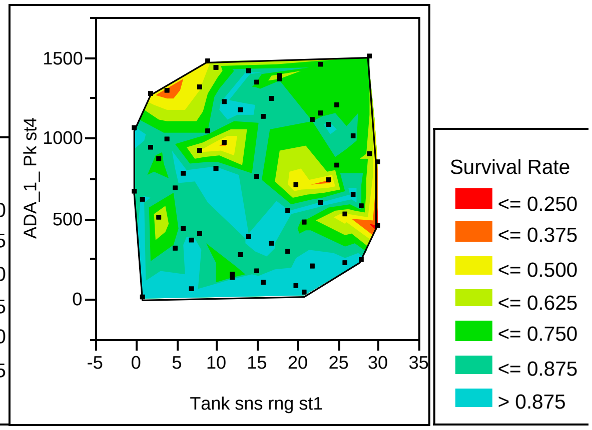
Pareto Plot of Estimates

Term	t Ratio
UAV speed	8.415450
ADA_1_ sns rng st4	-7.742962
ADA_1_ Pk st4	-6.331888
UAV Stealth	4.131012
(Tank sns rng st1-15.0154)*(Tank sns rng st1-15.0154)	-3.575630
(Tank sns rng st1-15.0154)*(Inf _3_ Pk pt1 st1-15.5077)	-3.039364
(Tank sns rng st1-15.0154)*(ADA_1_ Pk st4-755.015)	2.470500
(UAV sns rng-26.5077)*(UAV speed-117.062)	-2.296789
Tank sns rng st1	-1.852867
UAV sns rng	1.530789
Inf _3_ Pk pt1 st1	-1.196344



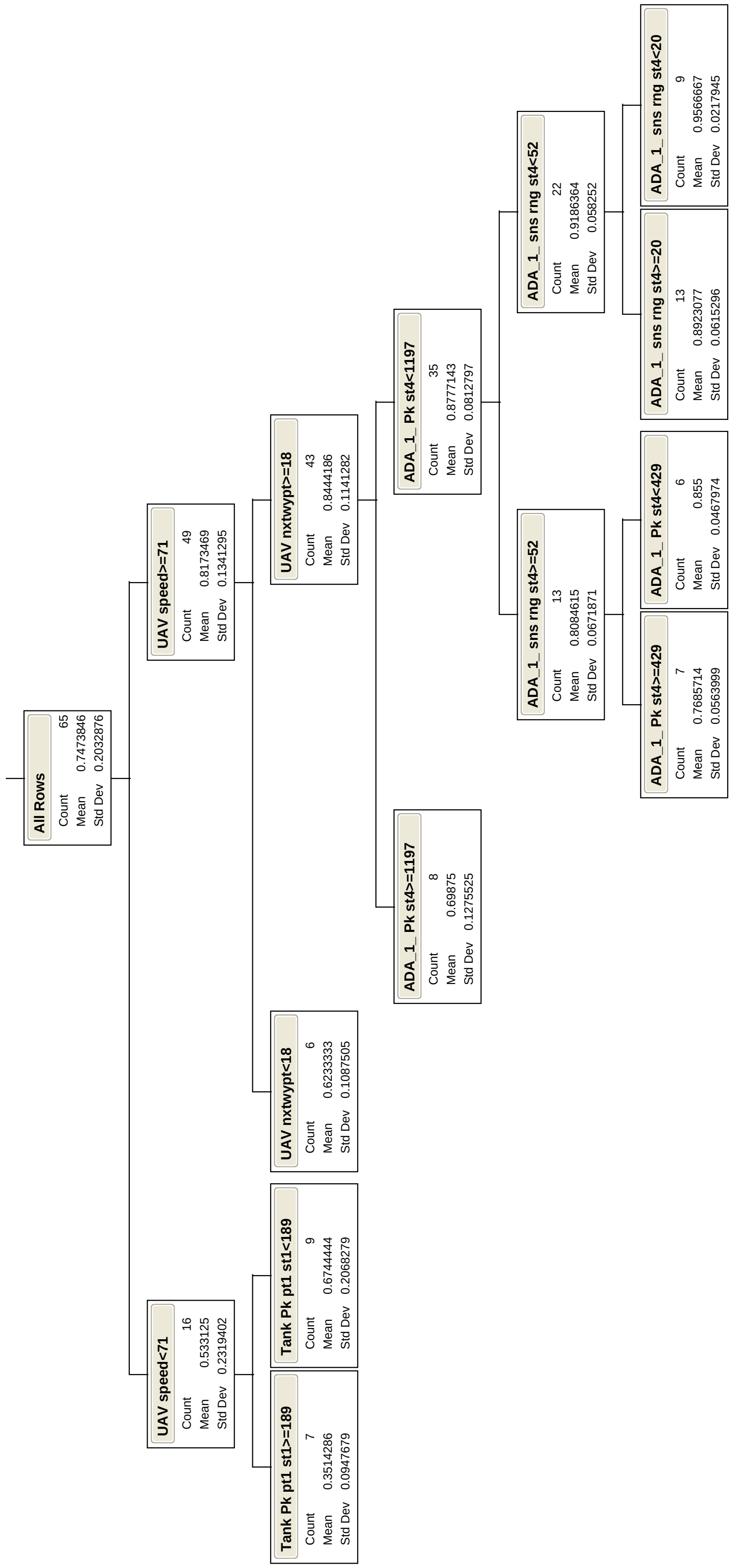
Contour Plots for Survival Rate





Partition for Survival Rate

RSquare	N	Imputes
0.755	65	0



Nominal Logistic Fit for Blue survive

Whole Model Test

Model	-LogLikelihood	DF	ChiSquare	Prob>ChiSq
Difference	702.8190	35	1405.638	<.0001
Full	2970.9176			
Reduced	3673.7366			

RSquare (U)	0.1913
Observations (or Sum Wgts)	6500

Converged by Gradient

Lack Of Fit

Source	DF	-LogLikelihood	ChiSquare
Lack Of Fit	29	11.9130	23.82602
Saturated	64	2959.0045	Prob>ChiSq
Fitted	35	2970.9176	0.7375

Parameter Estimates

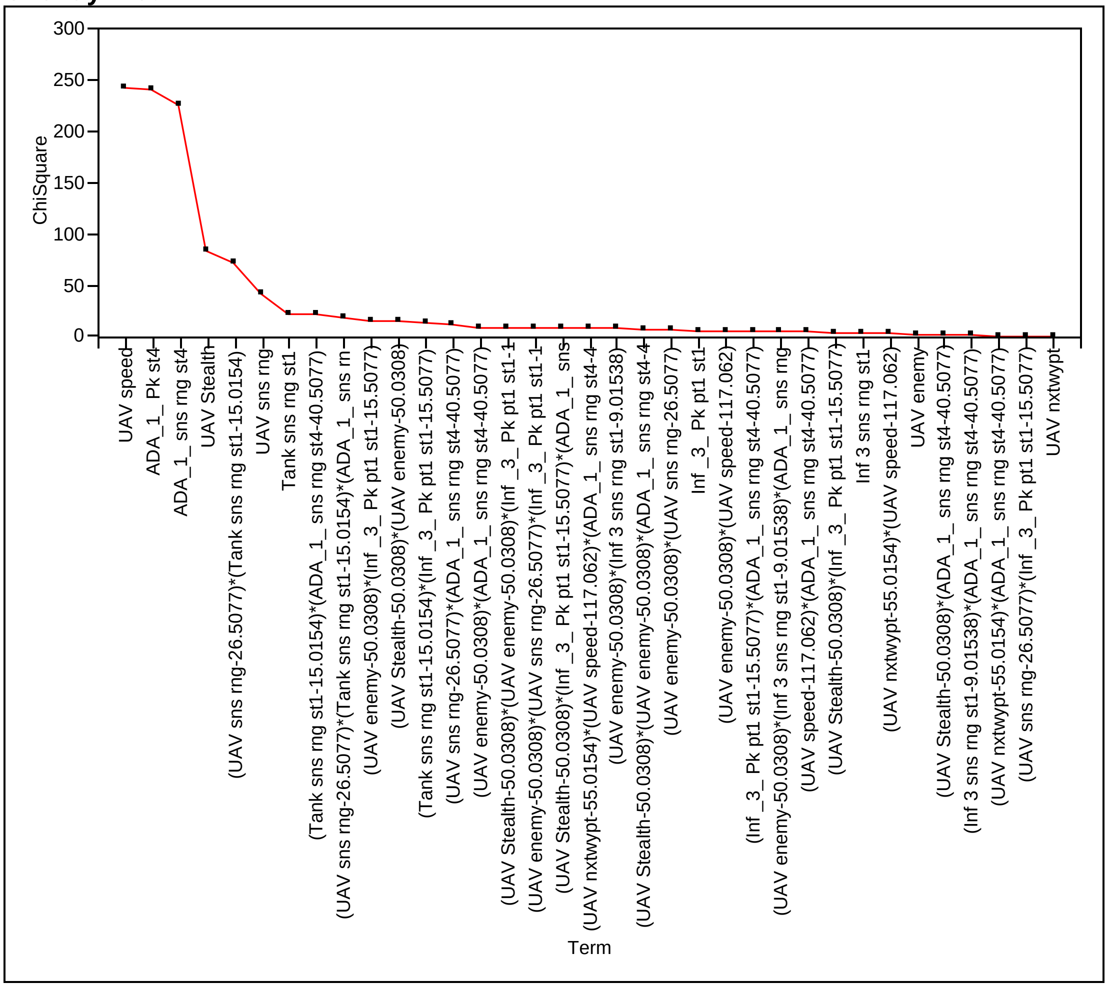
Term	Estimate	Std Error	ChiSquare	Prob>ChiSq
Intercept	-1.3500859	0.2085906	41.89	<.0001
UAV Stealth	-0.0129102	0.0014132	83.45	<.0001
UAV enemy	-0.0019392	0.0013611	2.03	0.1542
UAV nxtwypt	-0.000573	0.0014591	0.15	0.6945
UAV sns rng	-0.0184768	0.0028476	42.10	<.0001
UAV speed	-0.0116416	0.000749	241.55	<.0001
Tank sns rng st1	0.02203005	0.0047162	21.82	<.0001
Inf _3_ Pk pt1 st1	0.01160222	0.0050246	5.33	0.0209
Inf 3 sns rng st1	-0.0129003	0.0079623	2.62	0.1052
ADA_1_ sns rng st4	0.02652645	0.0017646	225.97	<.0001
ADA_1_ Pk st4	0.00140231	0.0000903	240.97	<.0001
(UAV Stealth-50.0308)*(UAV enemy-50.0308)	0.00022389	0.0000584	14.67	0.0001
(UAV Stealth-50.0308)*(Inf _3_ Pk pt1 st1-15.5077)	-0.0003282	0.0001924	2.91	0.0881
(UAV Stealth-50.0308)*(ADA_1_ sns rng st4-40.5077)	0.00018669	0.0001407	1.76	0.1844
(UAV enemy-50.0308)*(UAV sns rng-26.5077)	0.00030033	0.0001185	6.43	0.0112
(UAV enemy-50.0308)*(UAV speed-117.062)	0.00006245	0.0000283	4.89	0.0271
(UAV enemy-50.0308)*(Inf _3_ Pk pt1 st1-15.5077)	0.00066698	0.0001696	15.46	<.0001
(UAV enemy-50.0308)*(Inf 3 sns rng st1-9.01538)	-0.0010379	0.000379	7.50	0.0062
(UAV enemy-50.0308)*(ADA_1_ sns rng st4-40.5077)	-0.000155	0.0000534	8.42	0.0037
(UAV nxtwypt-55.0154)*(UAV speed-117.062)	-0.000085	0.0000525	2.62	0.1053
(UAV nxtwypt-55.0154)*(ADA_1_ sns rng st4-40.5077)	-0.0000445	0.0000664	0.45	0.5024
(UAV sns rng-26.5077)*(Tank sns rng st1-15.0154)	0.00323621	0.0003805	72.34	<.0001
(UAV sns rng-26.5077)*(Inf _3_ Pk pt1 st1-15.5077)	0.00029882	0.0007347	0.17	0.6842
(UAV sns rng-26.5077)*(ADA_1_ sns rng st4-40.5077)	0.00055647	0.000169	10.84	0.0010
(UAV speed-117.062)*(ADA_1_ sns rng st4-40.5077)	0.00007615	0.0000367	4.32	0.0377
(Tank sns rng st1-15.0154)*(Inf _3_ Pk pt1 st1-15.5077)	0.00237993	0.0006694	12.64	0.0004
(Tank sns rng st1-15.0154)*(ADA_1_ sns rng st4-40.5077)	-0.0012823	0.0002772	21.40	<.0001
(Inf _3_ Pk pt1 st1-15.5077)*(ADA_1_ sns rng st4-40.5077)	-0.0004099	0.0001869	4.81	0.0283
(Inf 3 sns rng st1-9.01538)*(ADA_1_ sns rng st4-40.5077)	-0.0003846	0.0003615	1.13	0.2873
(UAV Stealth-50.0308)*(UAV enemy-50.0308)*(Inf _3_ Pk pt1 st1-15.5077)	-0.00002	0.000007	8.06	0.0045
(UAV Stealth-50.0308)*(UAV enemy-50.0308)*(ADA_1_ sns rng st4-40.5077)	-0.0000092	0.0000035	6.79	0.0091
(UAV Stealth-50.0308)*(Inf _3_ Pk pt1 st1-15.5077)*(ADA_1_ sns rng st4-40.5077)	-0.0000285	0.0000103	7.65	0.0057
(UAV enemy-50.0308)*(UAV sns rng-26.5077)*(Inf _3_ Pk pt1 st1-15.5077)	0.00006384	0.0000227	7.94	0.0048
(UAV enemy-50.0308)*(Inf 3 sns rng st1-9.01538)*(ADA_1_ sns rng st4-40.5077)	-0.0000252	0.0000116	4.76	0.0292
(UAV nxtwypt-55.0154)*(UAV speed-117.062)*(ADA_1_ sns rng st4-40.5077)	0.00000429	0.0000016	7.56	0.0060
(UAV sns rng-26.5077)*(Tank sns rng st1-15.0154)*(ADA_1_ sns rng st4-40.5077)	-0.0001053	0.0000244	18.65	<.0001

For log odds of 0/1

Effect Wald Tests

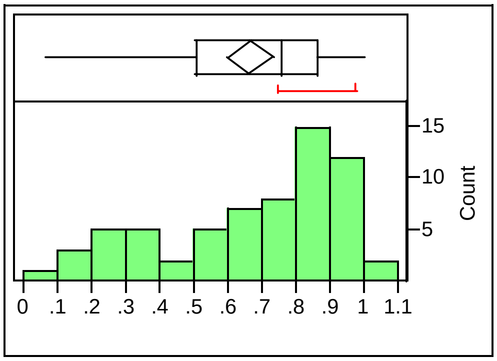
Source	Nparm	DF	Wald ChiSquare	Prob>ChiSq
UAV Stealth	1	1	83.4549691	0.0000
UAV enemy	1	1	2.02991163	0.1542
UAV nxtwypt	1	1	0.15420401	0.6945
UAV sns rng	1	1	42.1018211	0.0000
UAV speed	1	1	241.548338	0.0000
Tank sns rng st1	1	1	21.819547	0.0000
Inf _3_ Pk pt1 st1	1	1	5.33188052	0.0209
Inf 3 sns rng st1	1	1	2.62495641	0.1052
ADA_1_ sns rng st4	1	1	225.970943	0.0000
ADA_1_ Pk st4	1	1	240.969721	0.0000
UAV Stealth*UAV enemy	1	1	14.6737752	0.0001
UAV Stealth*Inf _3_ Pk pt1 st1	1	1	2.90869943	0.0881
UAV Stealth*ADA_1_ sns rng st4	1	1	1.76146267	0.1844
UAV enemy*UAV sns rng	1	1	6.42727422	0.0112
UAV enemy*UAV speed	1	1	4.88602184	0.0271
UAV enemy*Inf _3_ Pk pt1 st1	1	1	15.4616483	0.0001
UAV enemy*Inf 3 sns rng st1	1	1	7.49725441	0.0062
UAV enemy*ADA_1_ sns rng st4	1	1	8.41735364	0.0037
UAV nxtwypt*UAV speed	1	1	2.62375893	0.1053
UAV nxtwypt*ADA_1_ sns rng st4	1	1	0.44994235	0.5024
UAV sns rng*Tank sns rng st1	1	1	72.3383073	0.0000
UAV sns rng*Inf _3_ Pk pt1 st1	1	1	0.1654219	0.6842
UAV sns rng*ADA_1_ sns rng st4	1	1	10.8400887	0.0010
UAV speed*ADA_1_ sns rng st4	1	1	4.31714091	0.0377
Tank sns rng st1*Inf _3_ Pk pt1 st1	1	1	12.6413521	0.0004
Tank sns rng st1*ADA_1_ sns rng st4	1	1	21.3987603	0.0000
Inf _3_ Pk pt1 st1*ADA_1_ sns rng st4	1	1	4.80923033	0.0283
Inf 3 sns rng st1*ADA_1_ sns rng st4	1	1	1.13228623	0.2873
UAV Stealth*UAV enemy*Inf _3_ Pk pt1 st1	1	1	8.06287307	0.0045
UAV Stealth*UAV enemy*ADA_1_ sns rng st4	1	1	6.79341486	0.0091
UAV Stealth*Inf _3_ Pk pt1 st1*ADA_1_ sns rng st4	1	1	7.65466703	0.0057
UAV enemy*UAV sns rng*Inf _3_ Pk pt1 st1	1	1	7.94187377	0.0048
UAV enemy*Inf 3 sns rng st1*ADA_1_ sns rng st4	1	1	4.75790422	0.0292
UAV nxtwypt*UAV speed*ADA_1_ sns rng st4	1	1	7.56142753	0.0060
UAV sns rng*Tank sns rng st1*ADA_1_ sns rng st4	1	1	18.6468979	0.0000

Overlay Plot



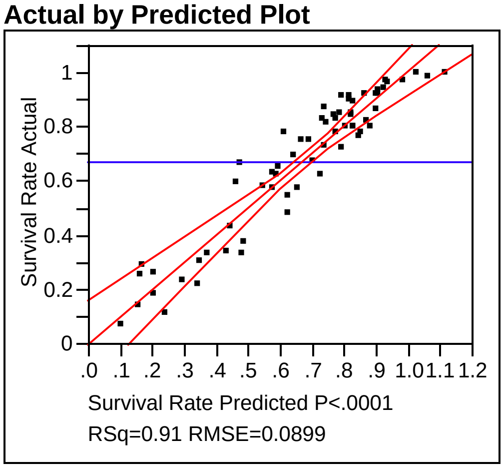
11. 3 X THREAT LEVEL SPREAD

Distributions
Survival Rate



Moments	
Mean	0.6690769
Std Dev	0.2605446
Std Err Mean	0.0323166
upper 95% Mean	0.7336367
lower 95% Mean	0.6045171
N	65

Response Survival Rate
Actual by Predicted Plot



Summary of Fit

RSquare	0.908834
RSquare Adj	0.880926
Root Mean Square Error	0.089906
Mean of Response	0.669077
Observations (or Sum Wgts)	65

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	15	3.9484693	0.263231	32.5654
Error	49	0.3960753	0.008083	Prob > F
C. Total	64	4.3445446		<.0001

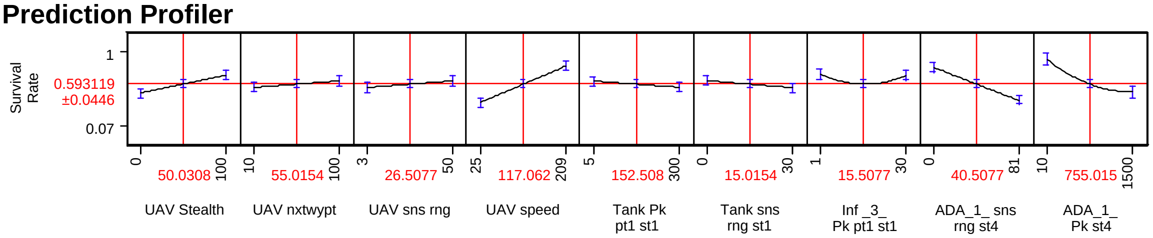
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.6019095	0.065973	9.12	<.0001
UAV Stealth	0.0021993	0.000381	5.78	<.0001
UAV nxtwypt	0.0008963	0.000422	2.12	0.0389
UAV sns rng	0.0017418	0.000808	2.16	0.0361
UAV speed	0.0024406	0.000207	11.80	<.0001
Tank Pk pt1 st1	-0.000263	0.000129	-2.04	0.0469
Tank sns rng st1	-0.002969	0.001263	-2.35	0.0228
Inf _3_ Pk pt1 st1	-0.000617	0.001309	-0.47	0.6395
ADA_1_ sns rng st4	-0.005046	0.00047	-10.74	<.0001
ADA_1_ Pk st4	-0.000267	0.000026	-10.44	<.0001
(UAV sns rng-26.5077)*(Tank sns rng st1-15.0154)	-0.000347	0.000107	-3.25	0.0021
(UAV speed-117.062)*(Tank Pk pt1 st1-152.508)	0.0000062	0.000002	2.50	0.0158
(UAV speed-117.062)*(ADA_1_ sns rng st4-40.5077)	0.000026	0.000009	2.89	0.0058
(ADA_1_ sns rng st4-40.5077)*(ADA_1_ Pk st4-755.015)	-0.000006	0.000001	-5.34	<.0001
(Inf _3_ Pk pt1 st1-15.5077)*(Inf _3_ Pk pt1 st1-15.5077)	0.0005442	0.00018	3.03	0.0039
(ADA_1_ Pk st4-755.015)*(ADA_1_ Pk st4-755.015)	1.8865e-7	7.333e-8	2.57	0.0132

Effect Tests 3X Threat, Spread

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
UAV Stealth	1	1	0.2698293	33.3816	<.0001
UAV nxtwypt	1	1	0.0364136	4.5049	0.0389
UAV sns rng	1	1	0.0375462	4.6450	0.0361
UAV speed	1	1	1.1255601	139.2474	<.0001
Tank Pk pt1 st1	1	1	0.0335968	4.1564	0.0469
Tank sns rng st1	1	1	0.0446989	5.5299	0.0228
Inf _3_ Pk pt1 st1	1	1	0.0017954	0.2221	0.6395
ADA_1_ sns rng st4	1	1	0.9315890	115.2505	<.0001
ADA_1_ Pk st4	1	1	0.8817817	109.0886	<.0001
UAV sns rng*Tank sns rng st1	1	1	0.0851648	10.5361	0.0021
UAV speed*Tank Pk pt1 st1	1	1	0.0505196	6.2500	0.0158
UAV speed*ADA_1_ sns rng st4	1	1	0.0673394	8.3308	0.0058
ADA_1_ sns rng st4*ADA_1_ Pk st4	1	1	0.2301531	28.4731	<.0001
Inf _3_ Pk pt1 st1*Inf _3_ Pk pt1 st1	1	1	0.0742214	9.1822	0.0039
ADA_1_ Pk st4*ADA_1_ Pk st4	1	1	0.0534986	6.6185	0.0132

Prediction Profiler

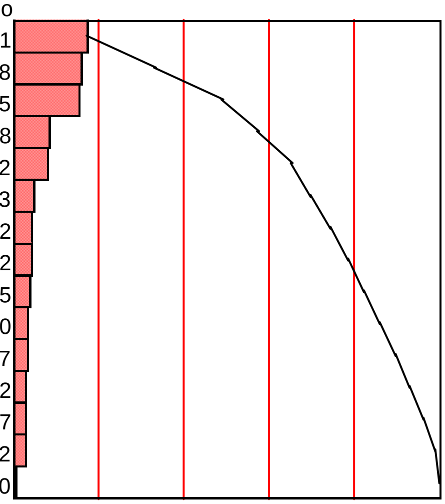


Effect Screening

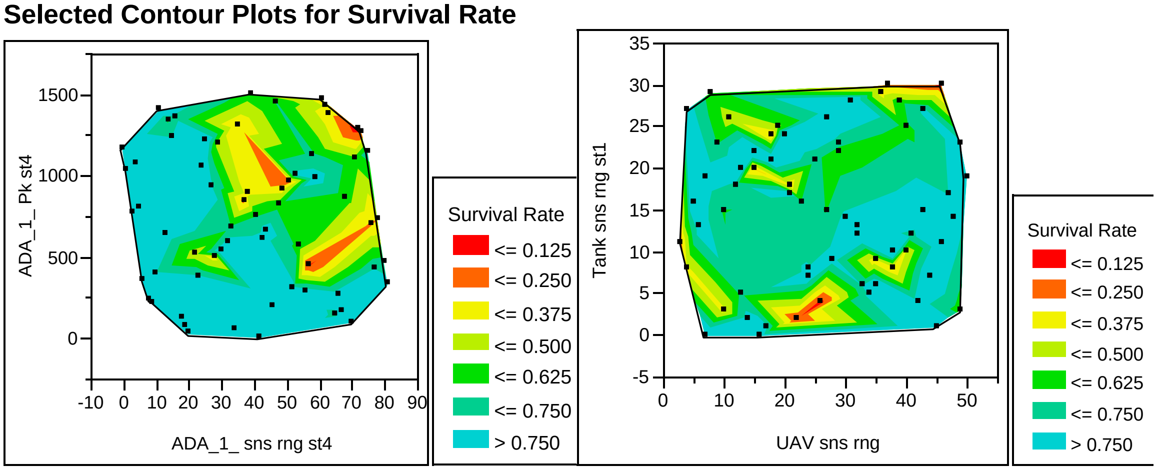
	Lenth PSE
t-Test Scale	4.1923095
Coded Scale	0.0467506

Pareto Plot of Estimates

Term	t Ratio
UAV speed	11.80031
ADA_1_ sns rng st4	-10.73548
ADA_1_ Pk st4	-10.44455
UAV Stealth	5.77768
(ADA_1_ sns rng st4-40.5077)*(ADA_1_ Pk st4-755.015)	-5.33602
(UAV sns rng-26.5077)*(Tank sns rng st1-15.0154)	-3.24593
(Inf _3_ Pk pt1 st1-15.5077)*(Inf _3_ Pk pt1 st1-15.5077)	3.03022
(UAV speed-117.062)*(ADA_1_ sns rng st4-40.5077)	2.88632
(ADA_1_ Pk st4-755.015)*(ADA_1_ Pk st4-755.015)	2.57265
(UAV speed-117.062)*(Tank Pk pt1 st1-152.508)	2.50000
Tank sns rng st1	-2.35157
UAV sns rng	2.15522
UAV nxtwypt	2.12247
Tank Pk pt1 st1	-2.03872
Inf _3_ Pk pt1 st1	-0.47130

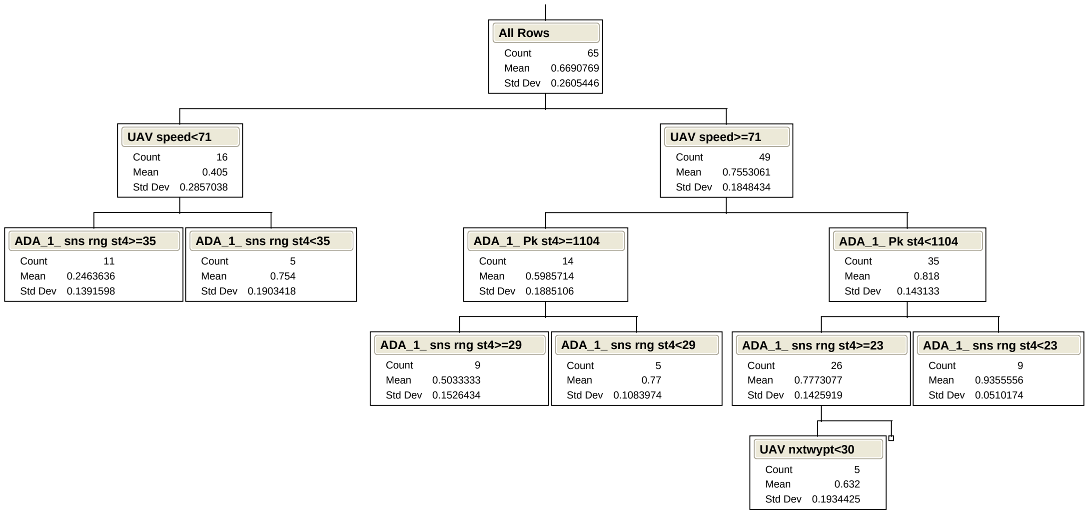


Selected Contour Plots for Survival Rate



Partition for Survival Rate

RSquare	N	Imputes
0.777	65	0



Nominal Logistic Fit for Blue survive
Whole Model Test

Model	-LogLikelihood	DF	ChiSquare	Prob>ChiSq
Difference	1043.7011	37	2087.402	0.0000
Full	3082.6966			
Reduced	4126.3977			

RSquare (U)	0.2529
Observations (or Sum Wgts)	6500

Converged by Gradient

Lack Of Fit

Source	DF	-LogLikelihood	ChiSquare
Lack Of Fit	27	10.0434	20.08677
Saturated	64	3072.6532	Prob>ChiSq
Fitted	37	3082.6966	0.8271

Parameter Estimates

Term	Estimate	Std Error	ChiSquare	Prob>ChiSq
Intercept	-0.8002765	0.2255965	12.58	0.0004
UAV Stealth	-0.0179694	0.0013427	179.11	<.0001
UAV enemy	0.00256735	0.0011735	4.79	0.0287
UAV nxtwypt	-0.0020386	0.0013685	2.22	0.1363
UAV sns rng	-0.0077936	0.0025444	9.38	0.0022
UAV speed	-0.0146741	0.000709	428.33	<.0001
Tank Pk pt1 st1	0.00198754	0.0004654	18.24	<.0001
Tank sns rng st1	0.00415958	0.0040744	1.04	0.3073
Inf _3_ Pk pt1 st1	-0.0065657	0.0045707	2.06	0.1509
Inf 3 sns rng st1	-0.0165869	0.007299	5.16	0.0231
ADA_1_ sns rng st4	0.03365076	0.0017724	360.47	<.0001
ADA_1_ Pk st4	0.00200179	0.0000911	482.64	<.0001
(UAV Stealth-50.0308)*(UAV enemy-50.0308)	0.0003461	0.0000824	17.63	<.0001
(UAV Stealth-50.0308)*(Tank sns rng st1-15.0154)	-0.0002884	0.0001647	3.07	0.0800
(UAV Stealth-50.0308)*(Inf _3_ Pk pt1 st1-15.5077)	-0.0001893	0.0002609	0.53	0.4680
(UAV Stealth-50.0308)*(Inf 3 sns rng st1-9.01538)	-0.0014129	0.0003368	17.60	<.0001
(UAV enemy-50.0308)*(UAV nxtwypt-55.0154)	-0.0001715	0.0000492	12.14	0.0005
(UAV enemy-50.0308)*(Inf _3_ Pk pt1 st1-15.5077)	-0.0002484	0.0002772	0.80	0.3701
(UAV enemy-50.0308)*(ADA_1_ Pk st4-755.015)	0.00000902	0.0000041	4.84	0.0279

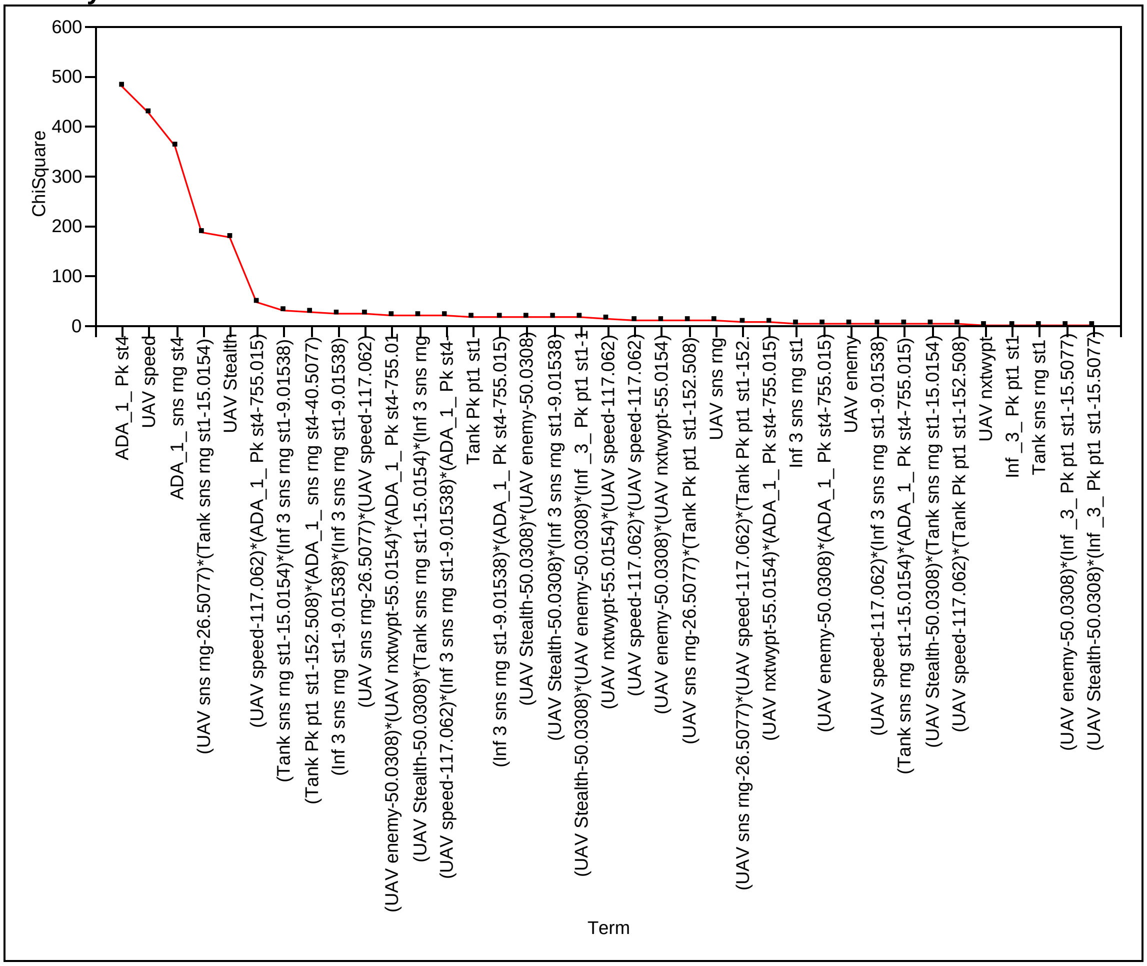
Term	Estimate	Std Error	ChiSquare	Prob>ChiSq
(UAV nxtwypt-55.0154)*(UAV speed-117.062)	0.00029806	0.0000837	12.67	0.0004
(UAV nxtwypt-55.0154)*(ADA_1_ Pk st4-755.015)	0.00001399	0.0000056	6.34	0.0118
(UAV sns rng-26.5077)*(UAV speed-117.062)	0.00031042	0.0000651	22.75	<.0001
(UAV sns rng-26.5077)*(Tank Pk pt1 st1-152.508)	0.00018037	0.0000543	11.03	0.0009
(UAV sns rng-26.5077)*(Tank sns rng st1-15.0154)	0.00489104	0.0003567	188.04	<.0001
(UAV speed-117.062)*(Tank Pk pt1 st1-152.508)	0.00001829	0.000011	2.78	0.0957
(UAV speed-117.062)*(Inf 3 sns rng st1-9.01538)	-0.000628	0.0002918	4.63	0.0314
(UAV speed-117.062)*(ADA_1_ Pk st4-755.015)	0.00002202	0.0000032	46.41	<.0001
(Tank Pk pt1 st1-152.508)*(ADA_1_ sns rng st4-40.5077)	0.00021709	0.0000416	27.26	<.0001
(Tank sns rng st1-15.0154)*(Inf 3 sns rng st1-9.01538)	-0.0148635	0.0026758	30.86	<.0001
(Tank sns rng st1-15.0154)*(ADA_1_ Pk st4-755.015)	-0.0000362	0.0000201	3.24	0.0718
(Inf 3 sns rng st1-9.01538)*(ADA_1_ Pk st4-755.015)	0.00010981	0.0000259	17.92	<.0001
(UAV Stealth-50.0308)*(UAV enemy-50.0308)*(Inf _3_ Pk pt1 st1-15.5077)	-0.0000266	0.0000065	16.80	<.0001
(UAV Stealth-50.0308)*(Tank sns rng st1-15.0154)*(Inf 3 sns rng st1-9.01538)	-0.0001853	0.0000407	20.69	<.0001
(UAV enemy-50.0308)*(UAV nxtwypt-55.0154)*(ADA_1_ Pk st4-755.015)	-4.2349e-7	9.2763e-8	20.84	<.0001
(UAV sns rng-26.5077)*(UAV speed-117.062)*(Tank Pk pt1 st1-152.508)	-0.0000017	6.7915e-7	6.44	0.0112
(UAV speed-117.062)*(Inf 3 sns rng st1-9.01538)*(ADA_1_ Pk st4-755.015)	0.00000219	4.9739e-7	19.40	<.0001
(UAV speed-117.062)*(UAV speed-117.062)	-0.0000614	0.0000175	12.33	0.0004
(Inf 3 sns rng st1-9.01538)*(Inf 3 sns rng st1-9.01538)	-0.009059	0.0018406	24.22	<.0001

For log odds of 0/1

Effect Wald Tests

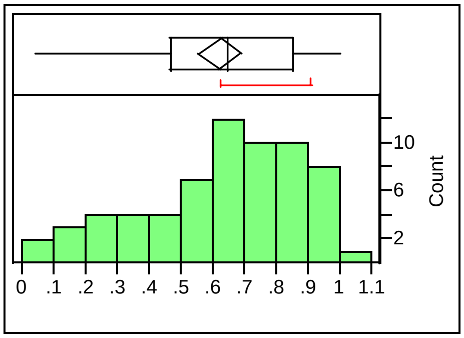
Source	Nparm	DF	Wald ChiSquare	Prob>ChiSq	
UAV Stealth	1	1	179.10926	0.0000	
UAV enemy	1	1	4.78631399	0.0287	
UAV nxtwypt	1	1	2.21905011	0.1363	
UAV sns rng	1	1	9.38179551	0.0022	
UAV speed	1	1	428.32618	0.0000	
Tank Pk pt1 st1	1	1	18.2404253	0.0000	
Tank sns rng st1	1	1	1.04227511	0.3073	
Inf _3_ Pk pt1 st1	1	1	2.06345541	0.1509	
Inf 3 sns rng st1	1	1	5.16412802	0.0231	
ADA_1_ sns rng st4	1	1	360.47138	0.0000	
ADA_1_ Pk st4	1	1	482.644137	0.0000	
UAV Stealth*UAV enemy	1	1	17.6301864	0.0000	
UAV Stealth*Tank sns rng st1	1	1	3.0651264	0.0800	
UAV Stealth*Inf _3_ Pk pt1 st1	1	1	0.52676626	0.4680	
UAV Stealth*Inf 3 sns rng st1	1	1	17.5975534	0.0000	
UAV enemy*UAV nxtwypt	1	1	12.138379	0.0005	
UAV enemy*Inf _3_ Pk pt1 st1	1	1	0.80329981	0.3701	
UAV enemy*ADA_1_ Pk st4	1	1	4.83729504	0.0279	
UAV nxtwypt*UAV speed	1	1	12.6725361	0.0004	
UAV nxtwypt*ADA_1_ Pk st4	1	1	6.33843714	0.0118	
UAV sns rng*UAV speed	1	1	22.7461186	0.0000	
UAV sns rng*Tank Pk pt1 st1	1	1	11.0336774	0.0009	
UAV sns rng*Tank sns rng st1	1	1	188.036875	0.0000	
UAV speed*Tank Pk pt1 st1	1	1	2.77520196	0.0957	
UAV speed*Inf 3 sns rng st1	1	1	4.63172169	0.0314	
UAV speed*ADA_1_ Pk st4	1	1	46.4124834	0.0000	
Tank Pk pt1 st1*ADA_1_ sns rng st4	1	1	27.2621114	0.0000	
Tank sns rng st1*Inf 3 sns rng st1	1	1	30.8551429	0.0000	
Tank sns rng st1*ADA_1_ Pk st4	1	1	3.24148399	0.0718	
Inf 3 sns rng st1*ADA_1_ Pk st4	1	1	17.9229642	0.0000	
UAV Stealth*UAV enemy*Inf _3_ Pk pt1 st1	1	1	16.799866	0.0000	
UAV Stealth*Tank sns rng st1*Inf 3 sns rng st1	1	1	20.6892185	0.0000	
UAV enemy*UAV nxtwypt*ADA_1_ Pk st4	1	0	0	0.0000	LostDFs
UAV sns rng*UAV speed*Tank Pk pt1 st1	1	0	0	0.0000	LostDFs
UAV speed*Inf 3 sns rng st1*ADA_1_ Pk st4	1	0	0	0.0000	LostDFs
UAV speed*UAV speed	1	1	12.3349564	0.0004	
Inf 3 sns rng st1*Inf 3 sns rng st1	1	1	24.2229507	0.0000	

Overlay Plot



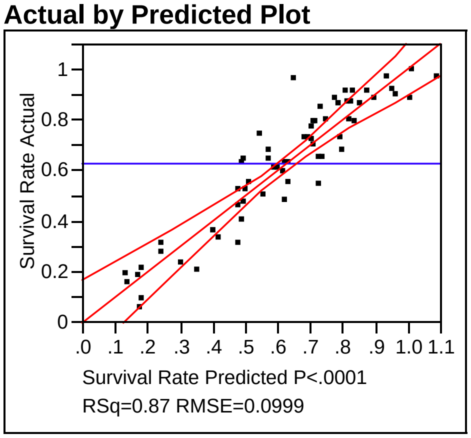
12. 3 X THREAT LEVEL DENSE

Distributions
Survival Rate



Moments	
Mean	0.6250769
Std Dev	0.2502257
Std Err Mean	0.0310367
upper 95% Mean	0.6870798
lower 95% Mean	0.563074
N	65

Response Survival Rate
Actual by Predicted Plot



Summary of Fit

RSquare	0.870618
RSquare Adj	0.840761
Root Mean Square Error	0.099852
Mean of Response	0.625077
Observations (or Sum Wgts)	65

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	12	3.4887622	0.290730	29.1592
Error	52	0.5184625	0.009970	Prob > F
C. Total	64	4.0072246		<.0001

Parameter Estimates

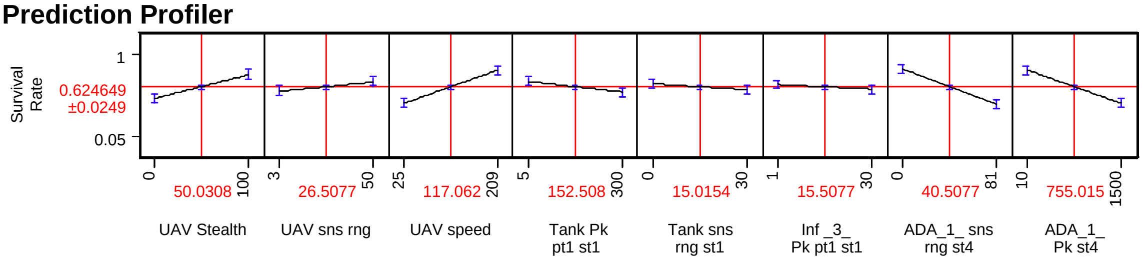
Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.7063125	0.065153	10.84	<.0001
UAV Stealth	0.002691	0.000423	6.37	<.0001
UAV sns rng	0.0022573	0.000898	2.51	0.0150
UAV speed	0.0020628	0.00023	8.98	<.0001
Tank Pk pt1 st1	-0.000404	0.000143	-2.82	0.0068
Tank sns rng st1	-0.002296	0.001402	-1.64	0.1077
Inf _3_ Pk pt1 st1	-0.001804	0.001454	-1.24	0.2203
ADA_1_ sns rng st4	-0.00497	0.000522	-9.52	<.0001
ADA_1_ Pk st4	-0.000255	0.000028	-8.98	<.0001
(UAV sns rng-26.5077)*(Tank sns rng st1-15.0154)	-0.000393	0.000103	-3.80	0.0004

Term	Estimate	Std Error	t Ratio	Prob>|t|
(UAV speed-117.062)*(Tank Pk pt1 st1-152.508)	0.000006	0.000003	2.22	0.0311
(Tank Pk pt1 st1-152.508)*(Inf _3_ Pk pt1 st1-15.5077)	-0.000068	0.000021	-3.15	0.0027
(ADA_1_ sns rng st4-40.5077)*(ADA_1_ Pk st4-755.015)	-0.000005	0.000001	-3.60	0.0007

Effect Tests 3X Threat Density

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
UAV Stealth	1	1	0.40396849	40.5166	<.0001
UAV sns rng	1	1	0.06305925	6.3246	0.0150
UAV speed	1	1	0.80409789	80.6482	<.0001
Tank Pk pt1 st1	1	1	0.07919662	7.9431	0.0068
Tank sns rng st1	1	1	0.02672036	2.6800	0.1077
Inf _3_ Pk pt1 st1	1	1	0.01534381	1.5389	0.2203
ADA_1_ sns rng st4	1	1	0.90397970	90.6661	<.0001
ADA_1_ Pk st4	1	1	0.80395617	80.6340	<.0001
UAV sns rng*Tank sns rng st1	1	1	0.14427044	14.4698	0.0004
UAV speed*Tank Pk pt1 st1	1	1	0.04894540	4.9091	0.0311
Tank Pk pt1 st1*Inf _3_ Pk pt1 st1	1	1	0.09922174	9.9516	0.0027
ADA_1_ sns rng st4*ADA_1_ Pk st4	1	1	0.12911238	12.9495	0.0007

Prediction Profiler

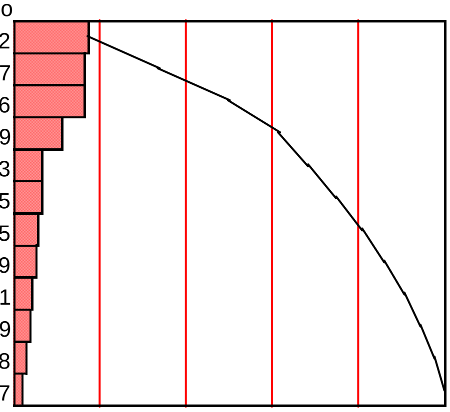


Effect Screening

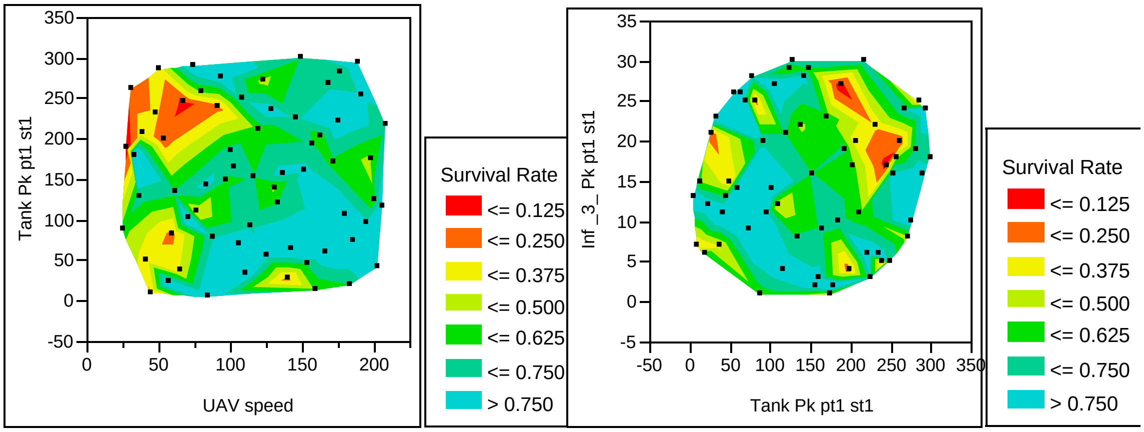
	Lenth PSE
t-Test Scale	4.8374258
Coded Scale	0.0599121

Pareto Plot of Estimates

Term	t Ratio
ADA_1_ sns rng st4	-9.521872
UAV speed	8.980437
ADA_1_ Pk st4	-8.979646
UAV Stealth	6.365269
(UAV sns rng-26.5077)*(Tank sns rng st1-15.0154)	-3.803923
(ADA_1_ sns rng st4-40.5077)*(ADA_1_ Pk st4-755.015)	-3.598545
(Tank Pk pt1 st1-152.508)*(Inf _3_ Pk pt1 st1-15.5077)	-3.154615
Tank Pk pt1 st1	-2.818359
UAV sns rng	2.514881
(UAV speed-117.062)*(Tank Pk pt1 st1-152.508)	2.215639
Tank sns rng st1	-1.637058
Inf _3_ Pk pt1 st1	-1.240537

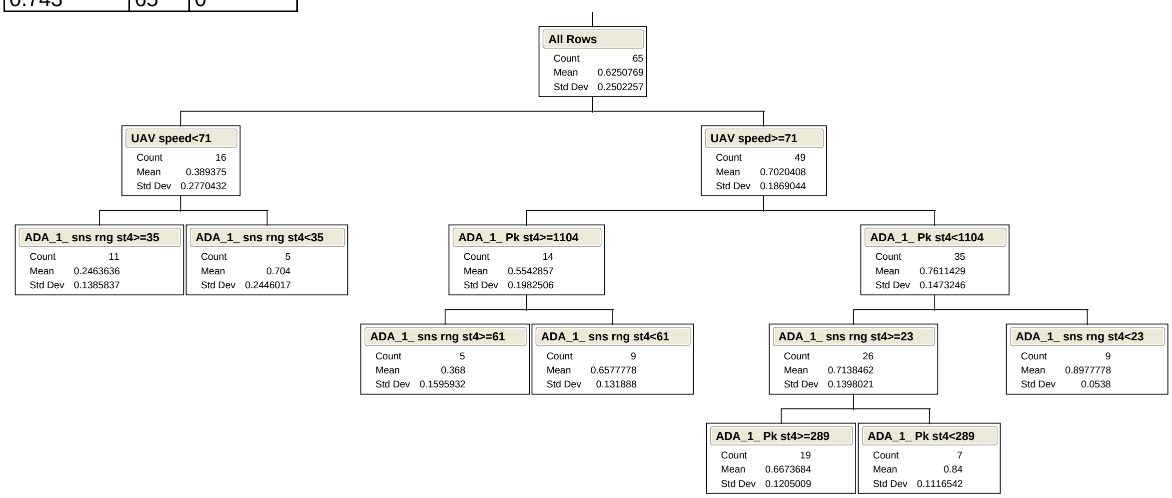


Contour Plots for Survival Rate



Partition for Survival Rate 3X Threat Density

RSquare	N	Imputes
0.743	65	0



Nominal Logistic Fit for Blue_Killed
Whole Model Test

Model	-LogLikelihood	DF	ChiSquare	Prob>ChiSq
Difference	879.7150	28	1759.43	0.0000
Full	3420.1906			
Reduced	4299.9056			

RSquare (U)	0.2046
Observations (or Sum Wgts)	6500

Converged by Objective

Lack Of Fit

Source	DF	-LogLikelihood	ChiSquare
Lack Of Fit	36	59.7797	119.5594
Saturated	64	3360.4109	Prob>ChiSq
Fitted	28	3420.1906	<.0001

Parameter Estimates

Term	Estimate	Std Error	ChiSquare	Prob>ChiSq
Intercept	0.80676676	0.190491	17.94	<.0001
UAV Stealth	0.01521099	0.0010648	204.07	<.0001
UAV enemy	0.00184344	0.0010422	3.13	0.0769
UAV nxtwypt	0.00134596	0.0011313	1.42	0.2342
UAV sns rng	0.01348866	0.0022419	36.20	<.0001

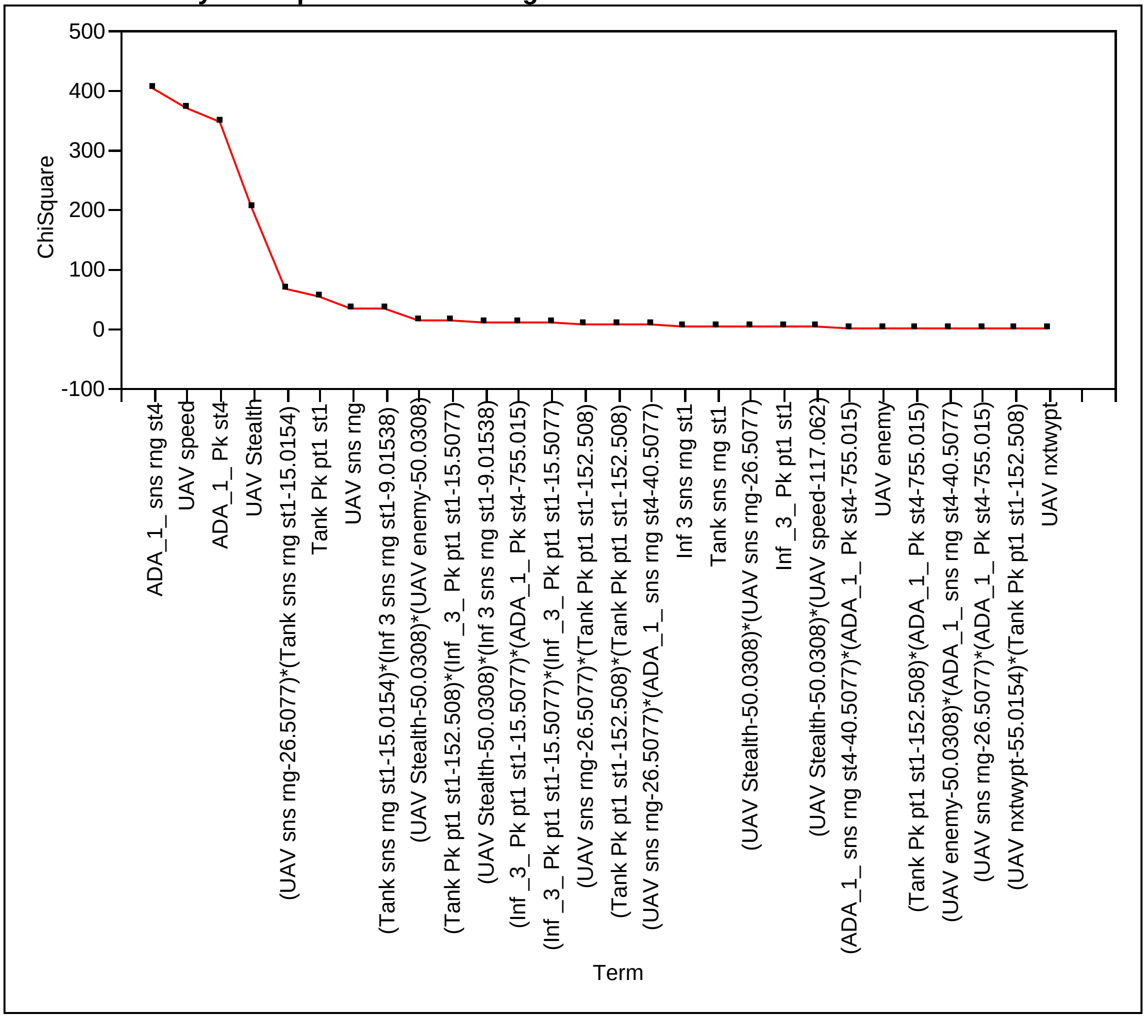
Term	Estimate	Std Error	ChiSquare	Prob>ChiSq
UAV speed	0.01134184	0.0005892	370.53	<.0001
Tank Pk pt1 st1	-0.0027974	0.000375	55.65	<.0001
Tank sns rng st1	-0.008457	0.003423	6.10	0.0135
Inf _3_ Pk pt1 st1	-0.007883	0.0035679	4.88	0.0271
Inf 3 sns rng st1	-0.0146104	0.0057582	6.44	0.0112
ADA_1_ sns rng st4	-0.0276932	0.0013738	406.38	<.0001
ADA_1_ Pk st4	-0.0014489	0.0000775	349.72	<.0001
(UAV Stealth-50.0308)*(UAV enemy-50.0308)	-0.000195	0.0000493	15.62	<.0001
(UAV Stealth-50.0308)*(UAV sns rng-26.5077)	-0.0001893	0.000082	5.33	0.0210
(UAV Stealth-50.0308)*(UAV speed-117.062)	-0.0000423	0.0000193	4.80	0.0285
(UAV Stealth-50.0308)*(Inf 3 sns rng st1-9.01538)	0.00090938	0.0002626	12.00	0.0005
(UAV enemy-50.0308)*(ADA_1_ sns rng st4-40.5077)	0.00006163	0.000038	2.63	0.1049
(UAV nxtwypt-55.0154)*(Tank Pk pt1 st1-152.508)	-0.0000284	0.0000218	1.70	0.1921
(UAV sns rng-26.5077)*(Tank Pk pt1 st1-152.508)	-0.0000794	0.000027	8.63	0.0033
(UAV sns rng-26.5077)*(Tank sns rng st1-15.0154)	-0.0028298	0.0003383	69.97	<.0001
(UAV sns rng-26.5077)*(ADA_1_ sns rng st4-40.5077)	-0.0004259	0.0001631	6.82	0.0090
(UAV sns rng-26.5077)*(ADA_1_ Pk st4-755.015)	0.00000933	0.000006	2.42	0.1199
(Tank Pk pt1 st1-152.508)*(Inf _3_ Pk pt1 st1-15.5077)	-0.0002571	0.0000658	15.25	<.0001
(Tank Pk pt1 st1-152.508)*(ADA_1_ Pk st4-755.015)	0.00000161	9.2973e-7	2.99	0.0837
(Tank sns rng st1-15.0154)*(Inf 3 sns rng st1-9.01538)	0.00511222	0.0008754	34.11	<.0001
(Inf _3_ Pk pt1 st1-15.5077)*(ADA_1_ Pk st4-755.015)	0.00003446	0.0000101	11.60	0.0007
(ADA_1_ sns rng st4-40.5077)*(ADA_1_ Pk st4-755.015)	-0.0000073	0.0000041	3.18	0.0747
(Tank Pk pt1 st1-152.508)*(Tank Pk pt1 st1-152.508)	0.00001931	0.0000067	8.28	0.0040
(Inf _3_ Pk pt1 st1-15.5077)*(Inf _3_ Pk pt1 st1-15.5077)	0.00183029	0.000546	11.24	0.0008

For log odds of 0/1

Effect Wald Tests

Source	Nparm	DF	Wald ChiSquare	Prob>ChiSq	
UAV Stealth	1	1	204.074535	0.0000	
UAV enemy	1	1	3.1285157	0.0769	
UAV nxtwypt	1	1	1.41538434	0.2342	
UAV sns rng	1	1	36.1994324	0.0000	
UAV speed	1	1	370.525457	0.0000	
Tank Pk pt1 st1	1	1	55.6521403	0.0000	
Tank sns rng st1	1	1	6.10419009	0.0135	
Inf _3_ Pk pt1 st1	1	1	4.881589	0.0271	
Inf 3 sns rng st1	1	1	6.43797672	0.0112	
ADA_1_ sns rng st4	1	1	406.376844	0.0000	
ADA_1_ Pk st4	1	1	349.721933	0.0000	
UAV Stealth*UAV enemy	1	1	15.6226069	0.0001	
UAV Stealth*UAV sns rng	1	1	5.32595907	0.0210	
UAV Stealth*UAV speed	1	1	4.79705912	0.0285	
UAV Stealth*Inf 3 sns rng st1	1	1	11.9950833	0.0005	
UAV enemy*ADA_1_ sns rng st4	1	1	2.62870217	0.1049	
UAV nxtwypt*Tank Pk pt1 st1	1	1	1.70133469	0.1921	
UAV sns rng*Tank Pk pt1 st1	1	1	8.62793904	0.0033	
UAV sns rng*Tank sns rng st1	1	1	69.9730555	0.0000	
UAV sns rng*ADA_1_ sns rng st4	1	1	6.81986812	0.0090	
UAV sns rng*ADA_1_ Pk st4	1	1	2.41883424	0.1199	
Tank Pk pt1 st1*Inf _3_ Pk pt1 st1	1	1	15.2458423	0.0001	
Tank Pk pt1 st1*ADA_1_ Pk st4	1	0	0	0.0000	LostDFs
Tank sns rng st1*Inf 3 sns rng st1	1	1	34.1058407	0.0000	
Inf _3_ Pk pt1 st1*ADA_1_ Pk st4	1	1	11.5982869	0.0007	
ADA_1_ sns rng st4*ADA_1_ Pk st4	1	1	3.17701662	0.0747	
Tank Pk pt1 st1*Tank Pk pt1 st1	1	1	8.27763317	0.0040	
Inf _3_ Pk pt1 st1*Inf _3_ Pk pt1 st1	1	1	11.238953	0.0008	

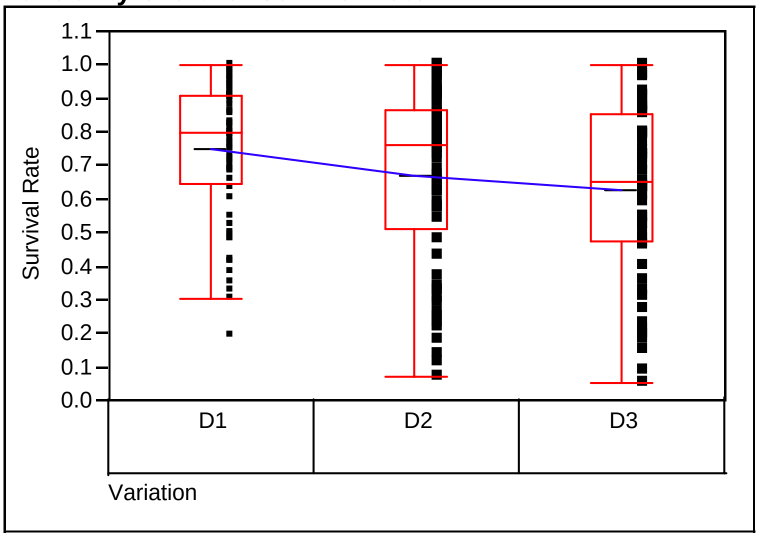
3X Threat Desity Chi Square Value Per Significant Term

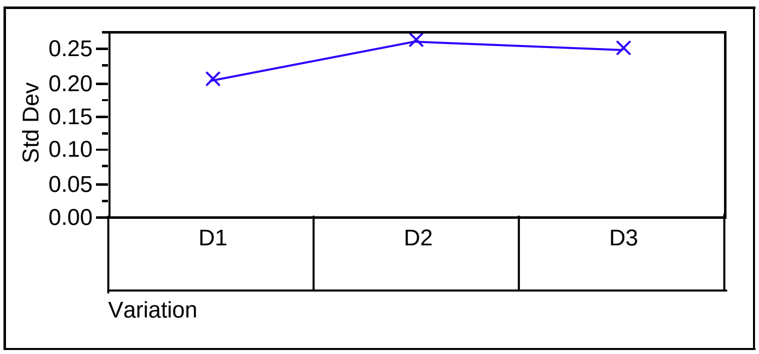


13. THREAT LEVEL SUMMARY

Variability Gage

Variability Chart for Survival Rate





Analysis of Variance

Source	DF	SS	Mean Square	F Ratio	Prob > F
Variation	2	0.498924	0.24946	4.35558	0.0141
Within	192	10.99662	0.05727		
Total	194	11.49555	0.05926		

Variance Components

Component	Var Component	% of Total	Plot%	Sqrt(Var Comp)
Variation	0.00295674	4.9		0.05438
Within	0.05727409	95.1		0.23932
Total	0.06023082	100.0		0.24542

APPENDIX C: CONVERSION TABLES

Distance Converter

From ↓ / To→

	Grid Squares	nm	mile	foot	km	meter
Grid Squares	**1.000**	0.159	0.183	968.8715	0.2953	295.3120
nm	6.271	**1.000**	1.151	6076.1155	1.8520	1852.0000
mile	5.450	0.869	**1.000**	5280.0000	1.6093	1609.3440
foot	0.001	0.000	0.000	**1.0000**	0.0003	0.3048
km	3.386	0.540	0.621	3280.8399	**1.0000**	1000.0000
meter	0.003	0.001	0.001	3.2808	0.0010	**1.0000**

Speed Converter

MANA	Knots	MPH	KPH
100	191.3469	220.1981	354.3745
52.2611	**100**	115.0779	185.2
45.41366	86.89762	**100**	160.9344
28.21874	53.99568	62.13712	**100**

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APPENDIX D: CLASSIFIED DATA

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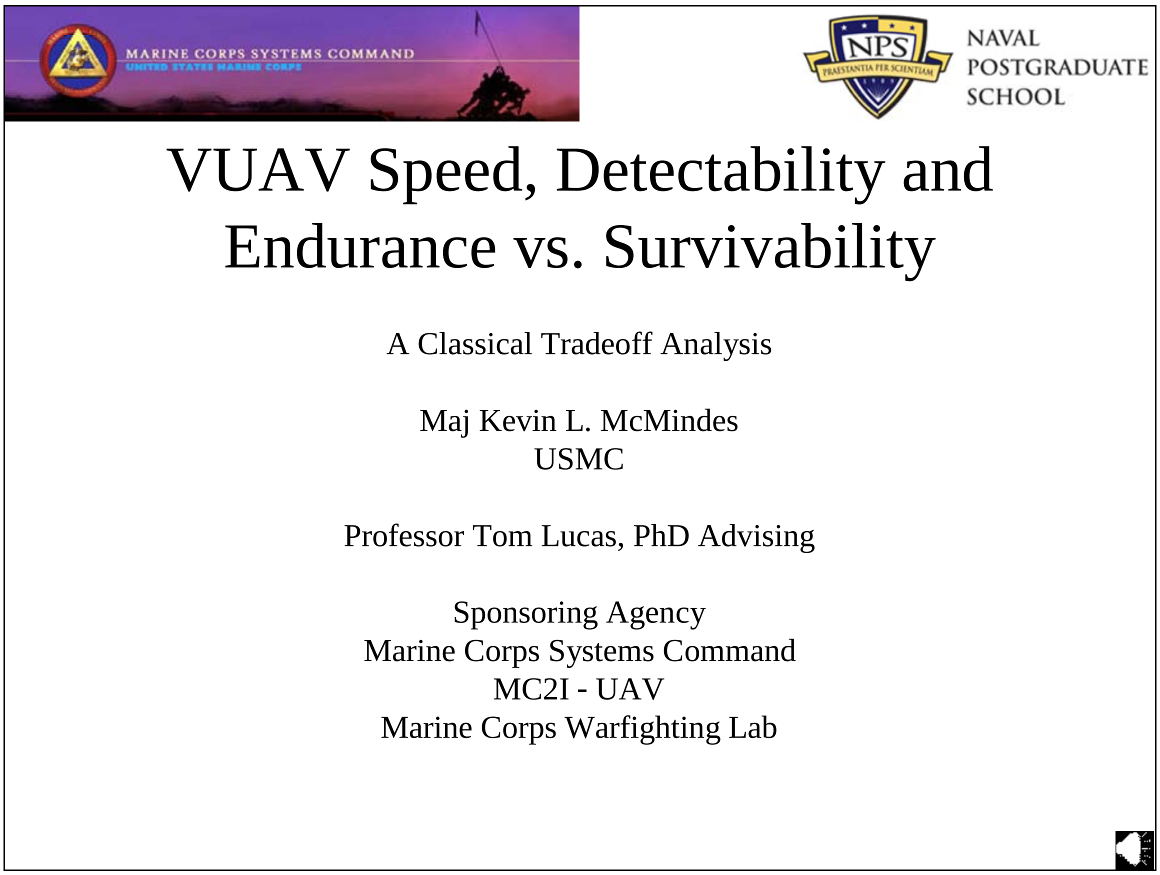
APPENDIX E: PRESENTATION OF FINDINGS TO MARINE CORPS SYSTEMS COMMAND

This appendix contains the entire brief given to Marine Corps System Command, M2CI, on 09 September 05. The .ppt file, including presenter notes, is available from the author or advisor.



"We no longer can treat UAVs as expendable. When these birds are taken out, there are huge gaps in our ability to act. We saw that happen in Kosovo."

-Bell Helicopter's senior vice president for U.S. government programs,

Gen. Terrance R. Dake (USMC Ret.)

Agenda

- Purpose and Scope
- Methods and Tools
- RESULTS!

Problem Statement

Explore the effects of speed, endurance, detectability, altitude, and enemy threat capabilities on ***survivability*** to assist in determination of design characteristics for the Vertical Unmanned Aerial Vehicle (VUAV).

Definitions

- **Survivability** - The capability of a system to avoid or withstand a hostile environment without suffering an abortive impairment of its ability to accomplish its designated mission.
- Can I use it again?

Background

- Pioneer UAV
- In service since 1986
- Schedule to retire in 2008
- Replacement will be Vertical UAV (VUAV) but it won't be fielded in time…

Interim System?

- Not yet selected
- These results will have an impact on both interim system and final system

My Job

- Find the importance and impact of speed, endurance, detectability, and altitude on survivability within the full range of enemy capabilities
- Not to get involved in preconceived judgments about which system is best for the Marine Corps
- Build upon previous MCWL sponsored thesis
  - addressed how well a UAV does its job over different parameters (speed, FOV, altitude, endurance, etc.)
  - MOE: UAV detections of enemy
- Focus on enemy detections and hits on UAV
  - MOE: Probability of survival

Methods and Tools

- Sea Viking 04 scenario
- MANA simulation
- Nearly Orthogonal Latin Hypercube Design
- Data Farming
- Analytical Tools
  - Classification Trees
  - Linear Regression
  - Logistic Regression

Sea Viking 04

- Recognized and approved mission and threat
- Comparative analysis to previous efficiency work
- Used previous scenario build with modification
  - Consistent behavior maintained

Sea Viking 04 – Forces Modeled

- Blue
  - 1 UAV
- Red
  - 4 Infantry Battalions
  - 1 Tank Battalion
  - 3 Air Defense Assets

Sources of Data

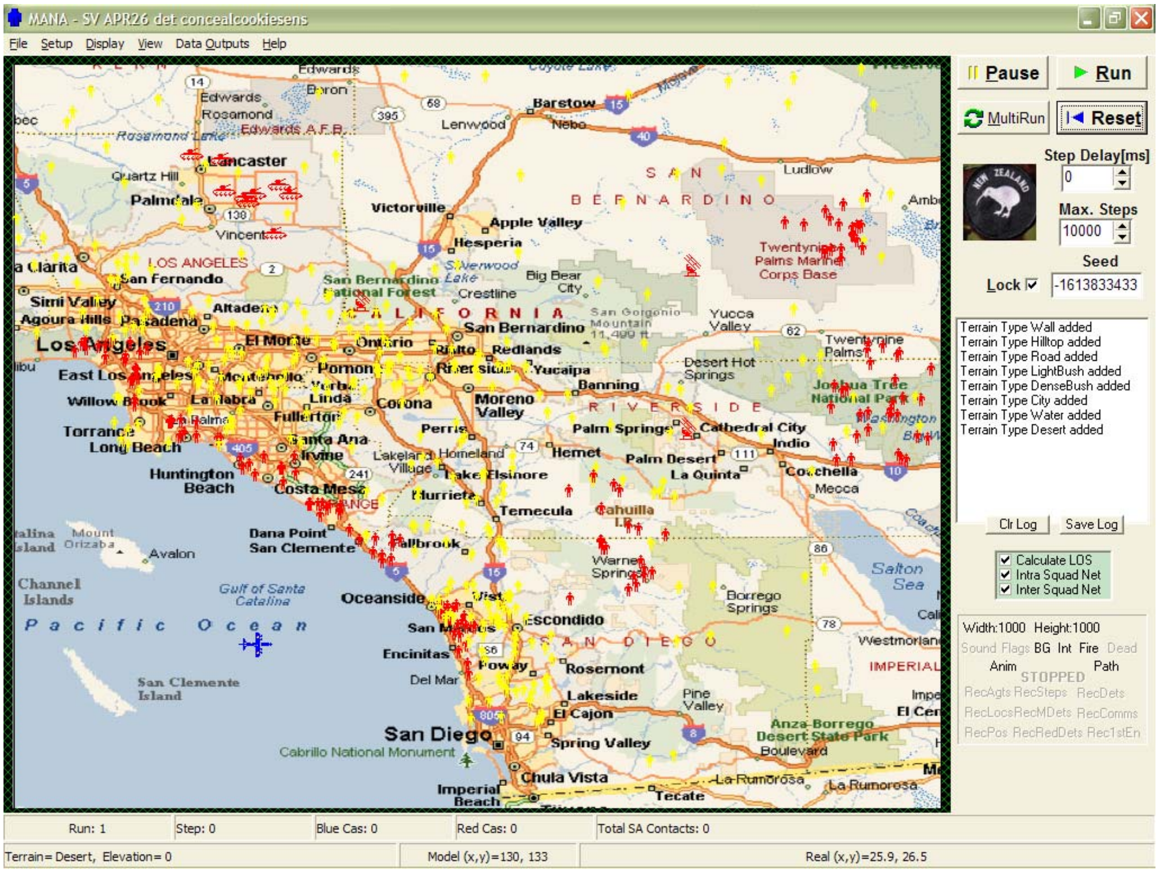
- Open source
  - Jane's All the Worlds Aircraft
  - Federation of American Scientist website
  - Program and Contractor web sites
- AMSAA
- SURVIAC

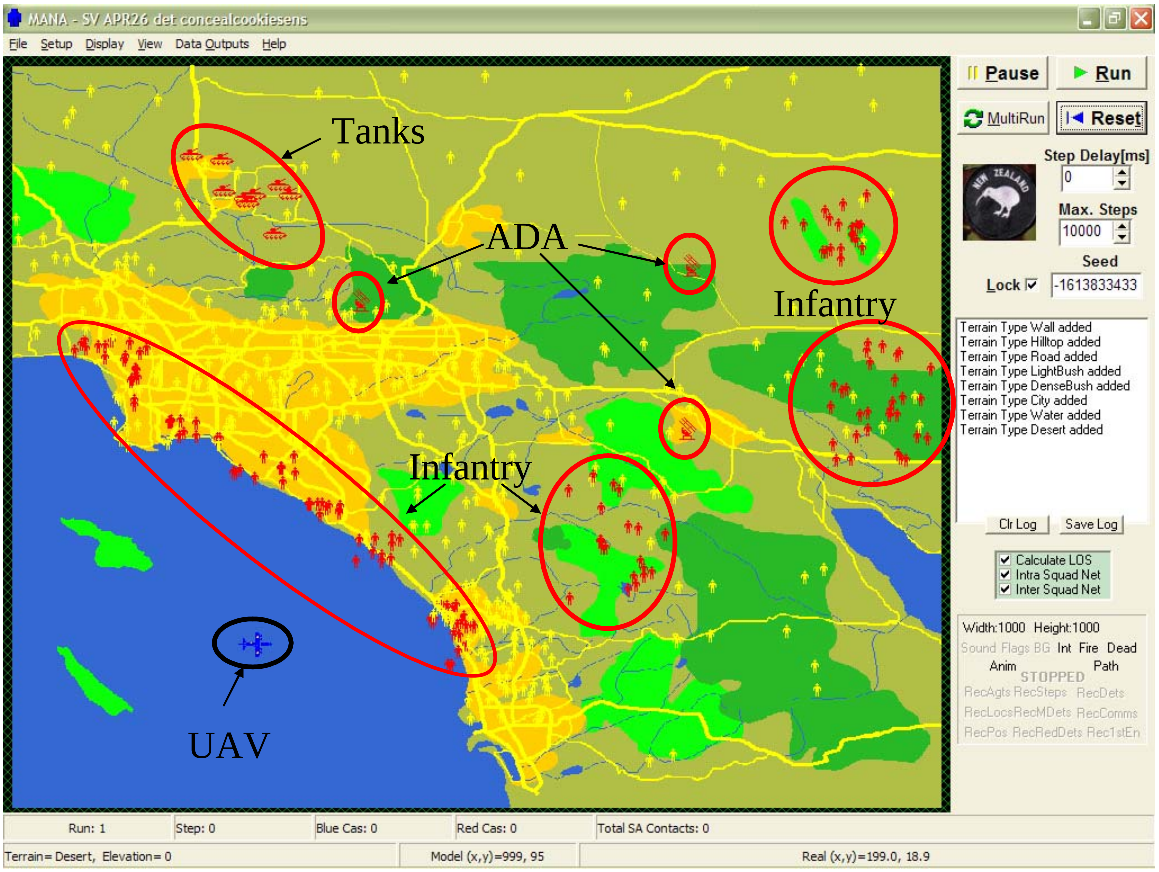
More about Data

- Initial Pks, sensor ranges and speed varied beyond expected capabilities.
- AMSAA data values verified to be within ranges used.

Map Aware Non-uniform Automata MANA

- Agent Based Model created by New Zealand Defense Force
- Individuals in squads of like personalities, sensor and weapons ranges
  - Personalities drive movement
  - State changes can give different attribute set
  - Situational Awareness / Comms



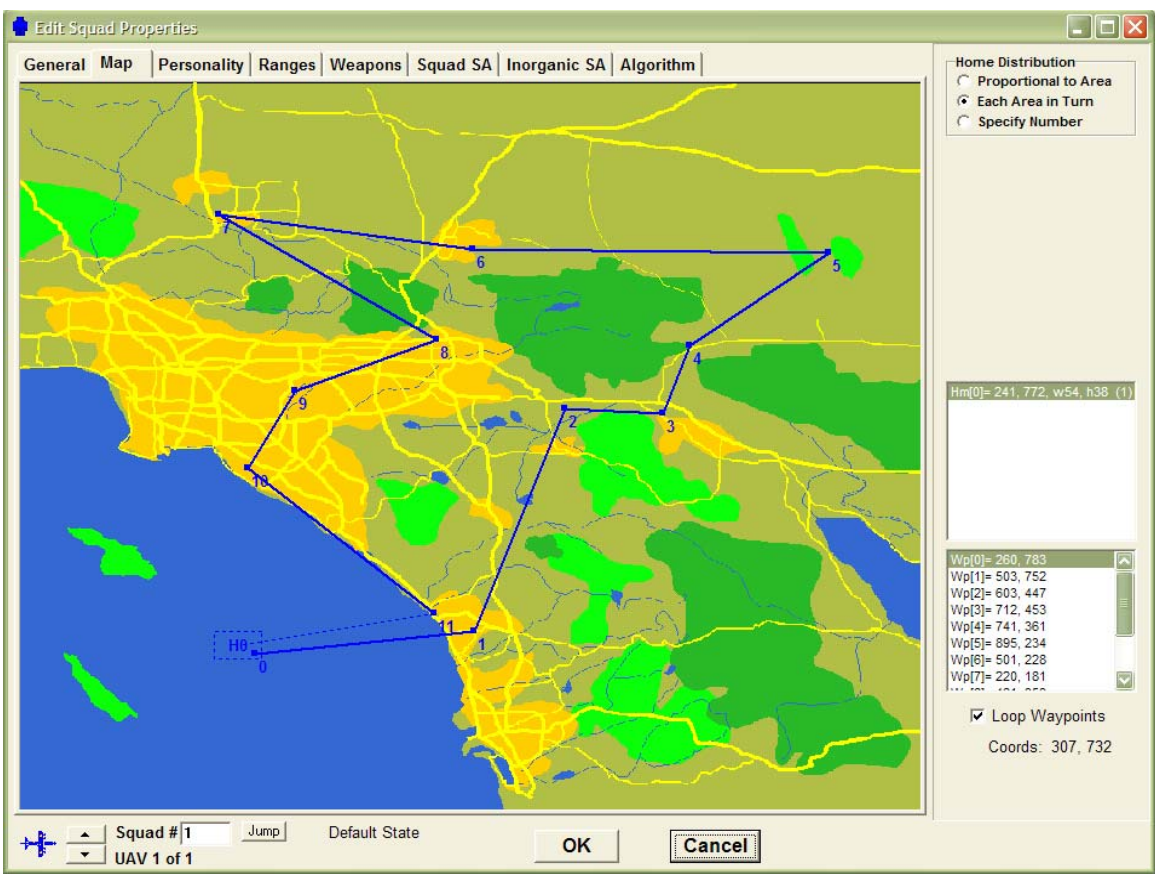


MANA Force Representations

- MANA Agent:
  - UAV
  - Infantry
  - Tank
  - Air Defense Asset
- Represents:
  - UAV
  - 3 Infantry
  - Hvy MG/ non-radar guided AAG
  - Man-pad / medium SAM and radar guided AAG

UAV Routing

- Tactical routing
  - Based on terrain and objectives
  - Likely enemy concentrations
  - Likely avenues of approach



Data Farming

- The application of high performance computing power to cultivate results from a vast range of variables in a simulation to explore the landscape of outcomes and analyze each factors importance.

Nearly Orthogonal Latin Hypercube

- Allows exploration decision space having many factors at many levels.
  - Traditional way: 65^{12} design points = 5,688,009,063,105,712,890,625 runs (without replication)
    - Run time: 1000's of years
  - NOLH way: 65 x 100 replications = 6500 runs per scenario.
    - Run time: 11 days (of CPU Time)

Factors Explored

- Blue Forces - 1 UAV
  - Stealth (0-100%)
  - Movement Speed (60-400knts)
  - Sensor Range (1-15km)
  - Alive enemy attraction
  - Next Waypoint attraction
  - Altitude* (1K, 5K, 10K)
- Note absence of Endurance
- Red Forces-
  - Probability of kill
  - Sensor range (UAV Stealth)
  - Tactical layout*
  - Threat Density/Volume*
- Consistent capabilities maintained within squads and like units

* Different Scenarios generated for these variations

Data Farming – Factors Varied

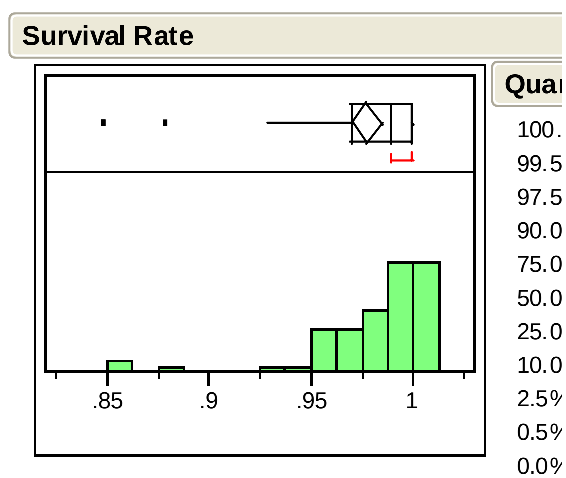
- WHY?
  - Discover value of UAV capabilities
  - Ensure robust solution in face of varied threat capabilities

Execution

- 10 Sceanrio Variations
- 65 design points in each variation
- 100 replications at each design point
- 65,000 total replications
- Executed at Maui High Performance Computer Center (very responsive support)

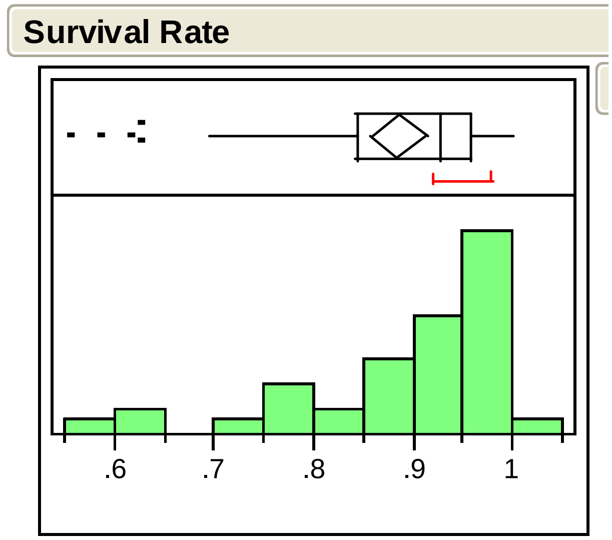
Results

- Base Run with initial values
  - Mean Survival Rate: 97.8%
  - Stealth and Speed tied for most important
  - UAV speed * ADA sensor range Interaction (+)
- Lacks sensitivity
  - Accelerated Life Testing – Simulation style
  - Increased all enemy Pk and sensor range values 3-fold.



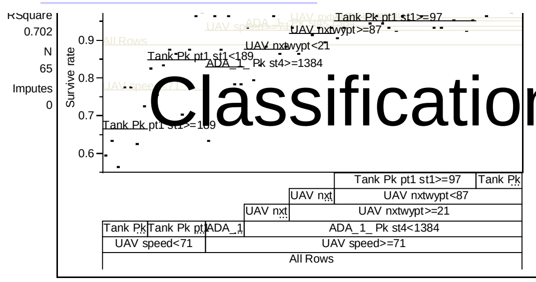
Results – Accelerated Base Case

1. **<u>Speed</u>** - by order of magnitude

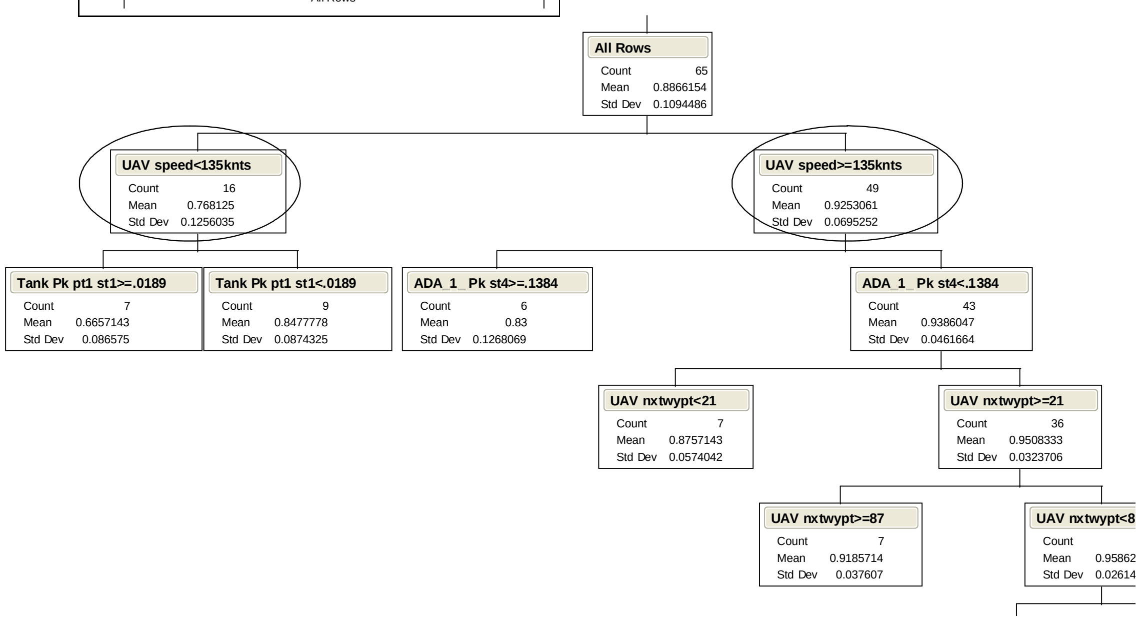


2. ADA sensor range
3. ADA Pk

Stepwise Linear Regression – Accelerated. Base



Classification Tree (CRT)

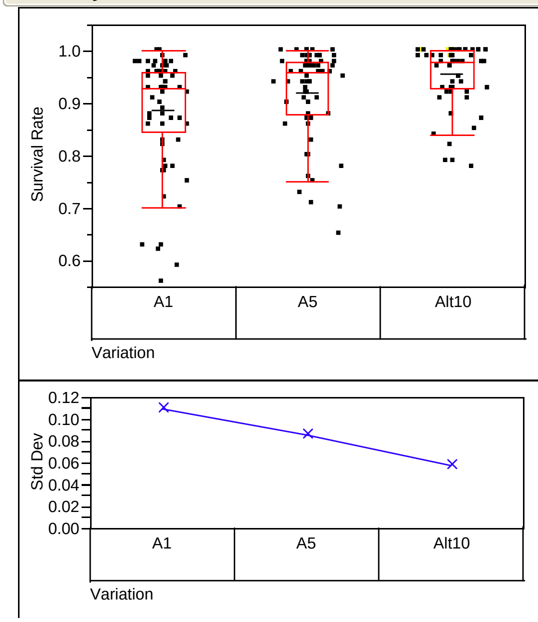


Results – Altitude Variations

- Higher altitudes yield greater survivability and less variation
- Importance of Speed over Stealth decreases with increasing altitude
- Speed break points (from CRT)
  - 135knts at 1K and 5K,
  - 118knts at 10K

Altitude: Linear Regression Comparison

Variability Chart for Survival Rate Across Altitude Scenarios

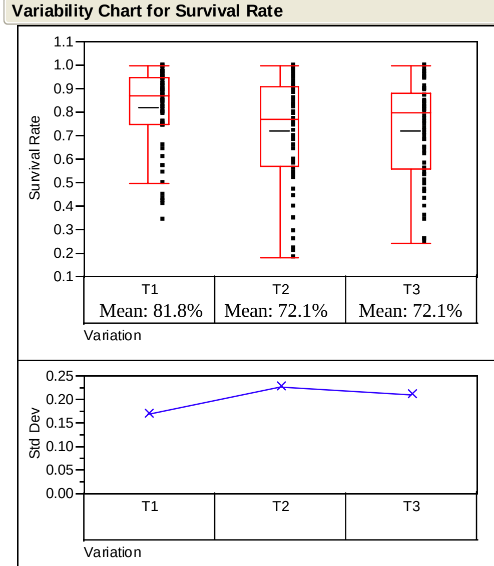


Analysis of Variance

Source	DF	SS	Mean Square	F Ratio	Prob > F
Variation	2	0.160001	0.08	10.4944	<.0001
Within	192	1.463652	0.00762		
Total	194	1.623653	0.00837		

Results – Tactical Layout Variations

Variability Chart for Survival Rate



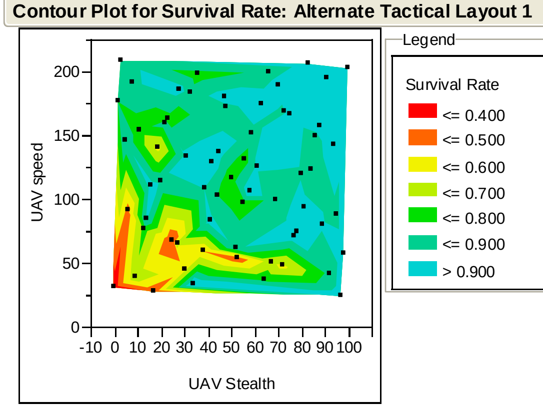
Analysis of Variance

Source	DF	SS	Mean Square	F Ratio	Prob > F
Variation	2	0.401283	0.20064	4.86165	0.0087
Within	192	7.923883	0.04127		
Total	194	8.325166	0.04291		

Variance Components

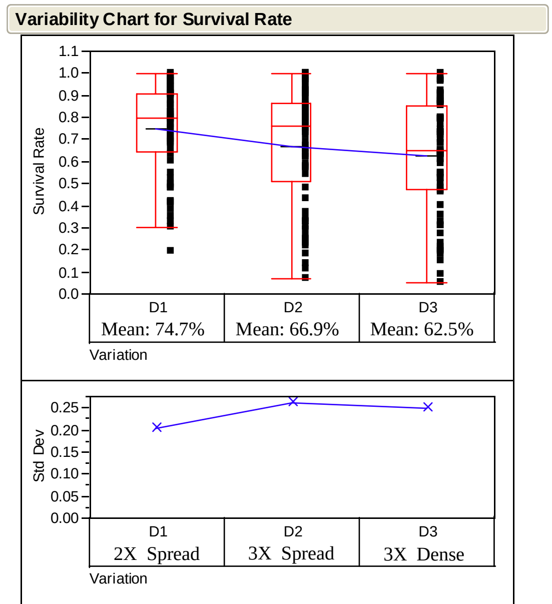
- Speed and Stealth about equal in T1
- Stealth dominates T2, T3 due to addition of Avenger
- Speed/Stealth interaction (-)

Contour Plot for Survival Rate: Alternate Tactical Layout 1



Results – Threat Density

- Speed
  - CRT break at 135knts
  - Top of both Spread versions, close 2nd Dense
- Dense or Spread no significant difference in mean of 3X runs
- Speed minimizes effect of higher enemy capabilities

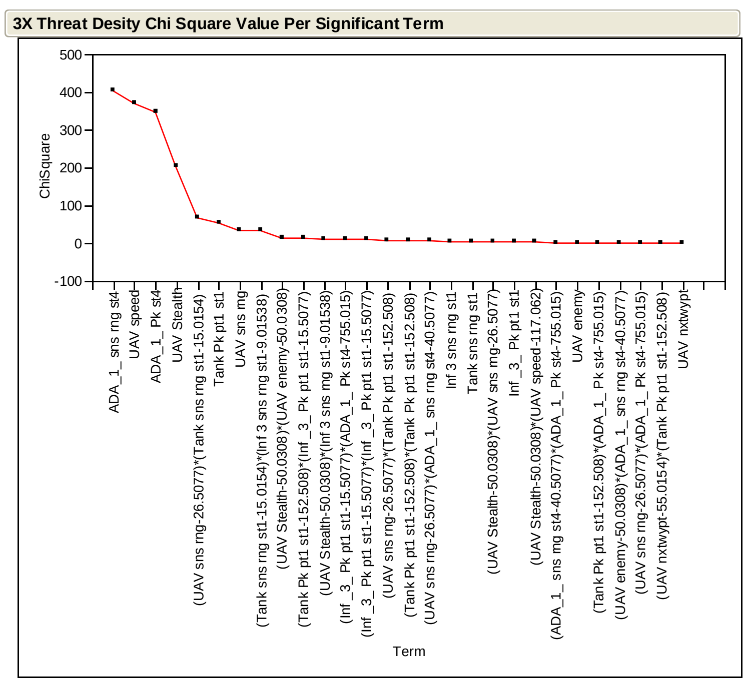


Analysis of Variance

Source	DF	SS	Mean Square	F Ratio	Prob > F
Variation	2	0.498924	0.24946	4.35558	0.0141
Within	192	10.99662	0.05727		
Total	194	11.49555	0.05926		

Why only mention a few factors?

- Significant factors
  - Linear regression: 8 to15
  - Logistic Regression: up to 34
- Statistical not Military Significance



Conclusions

- SPEED
  - Greater than 135 knts
  - Is sufficient except against very high threat capabilities.
  - In high threat high speed requires less stealth
- Stealth
  - Enemy detection range reduction more important than "camouflage"
  - Most important in presence of large, continuous ADA sensor range

Conclusions – Cont.

- Important Interactions
  - UAV Speed – Stealth gives diminishing return
  - UAV Speed – Enemy capabilities: Speed wins
  - ADA sensor range – ADA Pk: synergy when both present at high values (enemy point of view)

Linear Regression

- Start with all main effects, squared terms, and 2-way interactions.
- Stepwise AIC Reduction
- Fit regression
- Assumes normality
  - Using averages over design point Central Limit Theorem
  - Affects t-values and F-statistics slightly (no impact here)

Logistic Regression

- Uses raw data vice average across design point giving it more power and sensitivity
- Does not assume normality
- Low R-square values
- Supports Analysis of Linear Regression

Base Run Linear Regression

- R-square: 0.66

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
UAV Stealth	1	1	0.01144364	31.7390	<.0001
UAV speed	1	1	0.01048207	29.0721	<.0001
ADA2 sns rng st4	1	1	0.00347260	9.6313	0.0030
ADA2 Pk st4	1	1	0.00190968	5.2965	0.0250
UAV speed*ADA2 sns rng st4	1	1	0.00647320	17.9535	<.0001
UAV speed*ADA2 Pk st4	1	1	0.00206565	5.7291	0.0200
UAV speed*UAV speed	1	1	0.00247650	6.8686	0.0112

Stepwise Linear Regression – Accelerated. Base

Summary of Fit

RSquare	0.861132
RSquare Adj	0.822249
Root Mean Square Error	0.046144
Mean of Response	0.886615
Observations (or Sum Wgts)	65

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
UAV Stealth	1	1	0.01358922	6.3821	0.0147
UAV enemy	1	1	0.00023192	0.1089	0.7428
UAV sns rng	1	1	0.01910690	8.9734	0.0043
UAV speed	1	1	0.26717570	125.4774	<.0001
Tank Pk pt1 st1	1	1	0.04809503	22.5875	<.0001
Tank sns rng st1	1	1	0.01062432	4.9896	0.0300
ADA_1_ sns rng st4	1	1	0.08257426	38.7805	<.0001
ADA_1_ Pk st4	1	1	0.07113918	33.4101	<.0001
UAV enemy*UAV speed	1	1	0.02169529	10.1891	0.0024
UAV sns rng*Tank sns rng st1	1	1	0.05011618	23.5368	<.0001
UAV speed*Tank Pk pt1 st1	1	1	0.01173715	5.5123	0.0229
UAV speed*ADA_1_ sns rng st4	1	1	0.02186492	10.2687	0.0024
Tank Pk pt1 st1*ADA_1_ sns rng st4	1	1	0.01358824	6.3816	0.0147
ADA_1_ sns rng st4*ADA_1_ Pk st4	1	1	0.05458773	25.6368	<.0001

Return –

Altitude: Linear Regression Comparison

Effect Tests – 1000ft Altitude

Source	Sum of Squares	F Ratio	Prob > F
UAV Stealth	0.01358922	6.3821	0.0147
UAV enemy	0.00023192	0.1089	0.7428
UAV sns rng	0.01910690	8.9734	0.0043
UAV speed	0.26717570	125.4774	<.0001
Tank Pk pt1 st1	0.04809503	22.5875	<.0001
Tank sns rng st1	0.01062432	4.9896	0.0300
ADA_1_ sns rng st4	0.08257426	38.7805	<.0001
ADA_1_ Pk st4	0.07113918	33.4101	<.0001
UAV enemy*UAV speed	0.02169529	10.1891	0.0024
UAV sns rng*Tank sns rng st1	0.05011618	23.5368	<.0001
UAV speed*Tank Pk pt1 st1	0.01173715	5.5123	0.0229
UAV speed*ADA_1_ sns rng st4	0.02186492	10.2687	0.0024
Tank Pk pt1 st1*ADA_1_ sns rng st4	0.01358824	6.3816	0.0147
ADA_1_ sns rng st4*ADA_1_ Pk st4	0.05458773	25.6368	<.0001

Effect Tests - 5000ft Altitude

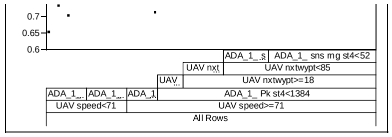
Source	Sum of Squares	F Ratio	Prob > F
UAV sns rng	0.01380867	6.7799	0.0117
UAV speed	0.13977423	68.6278	<.0001
Tank Pk pt1 st1	0.02913318	14.3041	0.0004
ADA_1_ sns rng st4	0.08587559	42.1641	<.0001
ADA_1_ Pk st4	0.04125264	20.2546	<.0001
UAV speed*ADA sns rng	0.02806648	13.7804	0.0005
ADA sns rng *ADA Pk	0.02113412	10.3766	0.0021

Effect Tests - 10,000ft Altitude

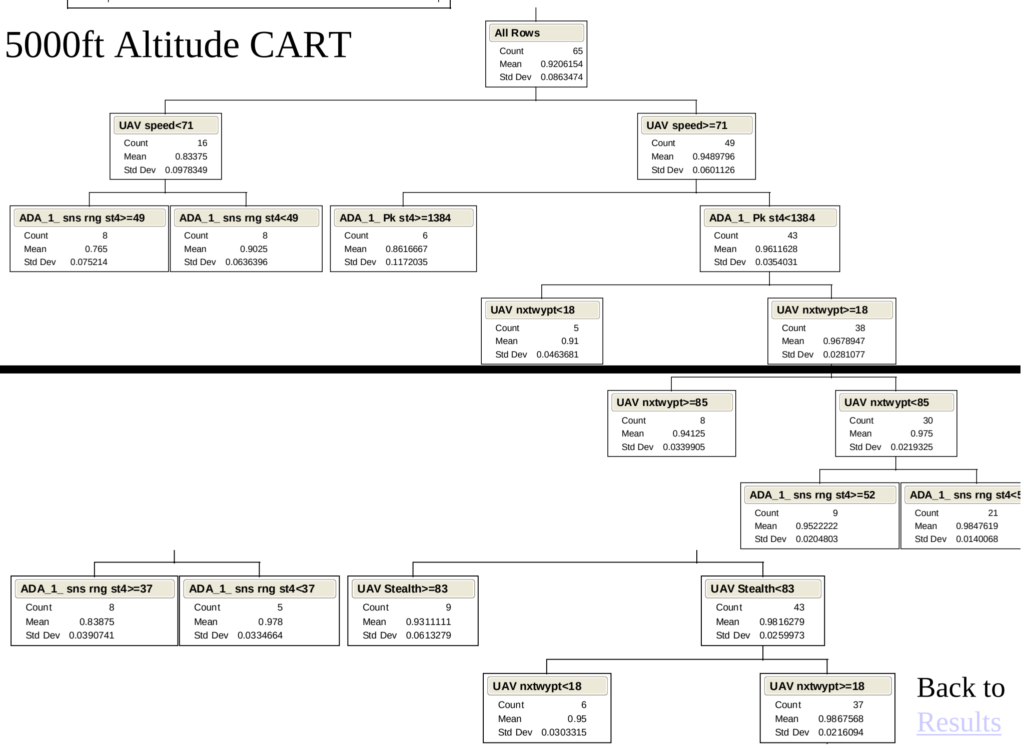
Source	Sum of Squares	F Ratio	Prob > F
UAV Stealth	0.01115033	11.5140	0.0013
UAV speed	0.04312951	44.5360	<.0001
ADA sns rng	0.04753680	49.0870	<.0001
ADA Pk	0.01799735	18.5843	<.0001
UAV Stealth*ADA Pk	0.00874321	9.0283	0.0040
UAV speed*ADA sns rng	0.02174887	22.4581	<.0001
ADA sns rng*ADA Pk	0.00697975	7.2074	0.0095
UAV speed*UAV speed1	0.00666616	6.8835	0.0112

Altitude Classification Tree

Back to Results – Altitude Variation



5000ft Altitude CART



Back to Results

Tactical Layout Linear Regres.

Effect Tests Alternate Tactical 1

Source	Sum of Squares	F Ratio	Prob > F
UAV Stealth	0.34005726	110.3946	<.0001
UAV speed	0.36625149	118.8982	<.0001
Tank Pk pt1 st1	0.03135504	10.1790	0.0025
Inf _3_ Pk pt1 st1	0.01543678	5.0113	0.0297
ADA_1_ sns rng st4	0.35090140	113.9150	<.0001
ADA_1_ Pk st4	0.20157198	65.4374	<.0001
UAV Stealth*UAV speed	0.03824057	12.4142	0.0009
UAV Stealth*ADA_1_ Pk st4	0.03113453	10.1074	0.0025
UAV speed*Inf _3_ Pk pt1 st1	0.03285973	10.6674	0.0020
UAV speed*ADA_1_ sns rng st4	0.02369136	7.6911	0.0078
UAV speed*ADA_1_ Pk st4	0.02517618	8.1731	0.0062
Tank Pk pt1 st1*Inf _3_ Pk pt1 st1	0.05260743	17.0782	0.0001
Inf _3_ Pk pt1 st1*ADA_1_ Pk st4	0.01436883	4.6646	0.0356
ADA_1_ sns rng st4*ADA_1_ Pk st4	0.08481969	27.5355	<.0001

Effect Tests Altenate Tactical 2

Source	Sum of Squares	F Ratio	Prob > F
UAV Stealth	0.55252711	84.3674	<.0001
UAV nxtwypt	0.00128528	0.1963	0.6597
UAV sns rng	0.04519704	6.9013	0.0115
UAV speed	0.28181358	43.0311	<.0001
Tank Pk pt1 st1	0.02116546	3.2318	0.0784
Tank sns rng st1	0.01388440	2.1201	0.1518
Inf _3_ Pk pt1 st1	0.00918893	1.4031	0.2419
ADA_1_ sns rng st4	0.76418946	116.6868	<.0001
ADA_1_ Pk st4	0.82482997	125.9463	<.0001
UAV Stealth*UAV speed	0.05658040	8.6395	0.0050
UAV Stealth*ADA_1_ sns rng st4	0.05032273	7.6840	0.0079
UAV nxtwypt*UAV sns rng	0.07072154	10.7987	0.0019
UAV sns rng*Tank sns rng st1	0.04550309	6.9480	0.0112
Tank Pk pt1 st1*Inf _3_ Pk pt1 st1	0.07630447	11.6512	0.0013
ADA_1_ sns rng st4*ADA_1_ Pk st4	0.17555260	26.8058	<.0001

Effect Tests Alternate Tactical 3

Source	Sum of Squares	F Ratio	Prob > F
UAV Stealth	0.44225821	95.3764	<.0001
UAV nxtwypt	0.00960578	2.0716	0.1563
UAV speed	0.20136899	43.4268	<.0001
Tank Pk pt1 st1	0.02116221	4.5638	0.0376
Tank sns rng st1	0.00414842	0.8946	0.3488
Inf 3 sns rng st1	0.00108169	0.2333	0.6312
ADA_1_ sns rng st4	0.76795445	165.6153	<.0001
ADA_1_ Pk st4	0.64346863	138.7690	<.0001
UAV Stealth*UAV speed	0.12398851	26.7391	<.0001
UAV nxtwypt*Tank Pk pt1 st1	0.04163560	8.9790	0.0042
UAV speed*ADA_1_ sns rng st4	0.02052082	4.4255	0.0405
Tank sns rng st1*Inf 3 sns rng st1	0.15961606	34.4224	<.0001
ADA_1_ sns rng st4*ADA_1_ Pk st4	0.02563854	5.5291	0.0227
Tank sns rng st1*Tank sns rng st1	0.06434829	13.8772	0.0005

Threat Density Linear Regression

Effect Tests 2X Threat, Spread

Source	Sum of Squares	F Ratio	Prob > F
UAV Stealth	0.16197314	17.0653	0.0001
UAV sns rng	0.02224133	2.3433	0.1318
UAV speed	0.67217871	70.8198	<.0001
Tank sns rng st1	0.03258508	3.4331	0.0695
Inf _3_ Pk pt1 st1	0.01358445	1.4312	0.2369
ADA_1_ sns rng st4	0.56904213	59.9535	<.0001
ADA_1_ Pk st4	0.38053674	40.0928	<.0001
UAV sns rng*UAV speed	0.05006941	5.2752	0.0256
Tank sns rng st1*Inf _3_ Pk pt1 st1	0.08767898	9.2377	0.0037
Tank sns rng st1*ADA_1_ Pk st4	0.05792950	6.1034	0.0167
Tank sns rng st1*Tank sns rng st1	0.12134872	12.7851	0.0008

Effect Tests 3X Threat, Spread

Source	Sum of Squares	F Ratio	Prob > F
UAV Stealth	0.2698293	33.3816	<.0001
UAV nxtwypt	0.0364136	4.5049	0.0389
UAV sns rng	0.0375462	4.6450	0.0361
UAV speed	1.1255601	139.2474	<.0001
Tank Pk pt1 st1	0.0335968	4.1564	0.0469
Tank sns rng st1	0.0446989	5.5299	0.0228
Inf _3_ Pk pt1 st1	0.0017954	0.2221	0.6395
ADA_1_ sns rng st4	0.9315890	115.2505	<.0001
ADA_1_ Pk st4	0.8817817	109.0886	<.0001
UAV sns rng*Tank sns rng st1	0.0851648	10.5361	0.0021
UAV speed*Tank Pk pt1 st1	0.0505196	6.2500	0.0158
UAV speed*ADA_1_ sns rng st4	0.0673394	8.3308	0.0058
ADA_1_ sns rng st4*ADA_1_ Pk st4	0.2301531	28.4731	<.0001
Inf _3_ Pk pt1 st1*Inf _3_ Pk pt1 st1	0.0742214	9.1822	0.0039
ADA_1_ Pk st4*ADA_1_ Pk st4	0.0534986	6.6185	0.0132

Effect Tests 3X Threat Density

Source	Sum of Squares	F Ratio	Prob > F
UAV Stealth	0.40396849	40.5166	<.0001
UAV sns rng	0.06305925	6.3246	0.0150
UAV speed	0.80409789	80.6482	<.0001
Tank Pk pt1 st1	0.07919662	7.9431	0.0068
Tank sns rng st1	0.02672036	2.6800	0.1077
Inf _3_ Pk pt1 st1	0.01534381	1.5389	0.2203
ADA_1_ sns rng st4	0.90397970	90.6661	<.0001
ADA_1_ Pk st4	0.80395617	80.6340	<.0001
UAV sns rng*Tank sns rng st1	0.14427044	14.4698	0.0004
UAV speed*Tank Pk pt1 st1	0.04894540	4.9091	0.0311
Tank Pk pt1 st1*Inf _3_ Pk pt1 st1	0.09922174	9.9516	0.0027
ADA_1_ sns rng st4*ADA_1_ Pk st4	0.12911238	12.9495	0.0007

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